Irish Journal of Agricultural and Food Research **48:** 189–207, 2009

Comparison of milk production from clover-based and fertilizer-N-based grassland on a clay-loam soil under moist temperate climatic conditions

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This study, conducted over four years (2003–2006), compared herbage production, nutritive value of herbage, the length of the grazing season and milk production per cow and per hectare from grassland systems based on (i) white clover (average 219 g/kg of herbage DM) (WC) receiving on average N application of 90 kg/ha (s.d. 6.4) in spring and successive 0.2 of the area over-seeded annually with white clover seed and (ii) fertilizer N (FN) input of 226 kg/ha (s.d. 9.7). The stocking density of Holstein-Friesian dairy cows on both systems was 2.0/ha 2003 and 2.2/ha in each of the following three years. There were 22 cows per system in 2003 and 24 cows per system in each of the following three years. Cows calved within a 12 week interval in spring with mean calving date in mid-February. Milk was produced until mid-December each year. Total annual herbage DM production was lower ($P < 0.01$) on WC than FN (0.92 of FN). There were no ($P > 0.05$) differences in the *in vitro* organic matter digestibilities of pre-grazing herbage. The crude protein concentration in pre-grazing herbage DM was higher ($P < 0.001$) on FN than WC: 219 and 209 (s.e. 8.4.) g/kg, respectively. There were no ($P > 0.05$) differences in annual production of milk per cow (mean 6524 kg; s.e. 83.9 kg), live-weight or body condition score between the two systems. There were no ($P < 0.05$) differences in the lengths of the grazing season, which averaged 254 days (s.e. 0.9). Although there was no difference in performance per cow, the higher herbage production indicates that a higher stocking rate and milk output per hectare was pos-

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sible from FN than WC. Nevertheless, the WC swards supported an annual stocking density of 2.15/ha and a milk output of 14 t/ha.

Keywords: dairy cows; grassland; milk production; nitrogen fertilizer; white clover

Introduction

In Ireland, grass/clover swards potentially can produce about 0.8 times the milk output from grass swards receiving N input of in excess of 350 kg ha^{-1} $annum^{-1}$. Milk produced from clover-based swards receiving no fertilizer N in a trial in Co Wexford was 0.87 that from grass receiving 387 kg/ha (Ryan, 1986). Although Humphreys, O'Connell and Casey (2008) found milk production from a clover-based system with cows stocked at 1.75/ha and an annual fertilizer N input of 80 kg/ha was 0.70 that from grass receiving 353 kg/ha, herbage production from the clover-based system was proportionately 0.80 of the intensive system; the stocking density of dairy cows was not sufficiently high to fully utilize all the herbage grown in the clover-based system. These relative production levels are in line with those from New Zealand. For example a clover-based system receiving no fertilizer N produced 0.80 of the herbage per ha (Ledgard *et al*., 2001) and 0.81 of the milk per ha (Ledgard, Crush and Penno, 1998) of a system receiving a fertilizer N input of 413 kg/ha per year over 5 grazing seasons.

The annual rate of fertilizer N input to the more intensive systems in the experiments described above are no longer permitted under Statutory Instruments (SI) No. 101 (2009) which implements the Nitrates Directive (European Council, 1991) in Ireland. Maximum allowable fertilizer N input to grassland is now linked to stocking density and is currently approximately 275 kg/ha for farms that have been granted a derogation from the more stringent limits of SI No. 101. Furthermore, the cost of fertilizer N has increased relative to milk price in recent years (CSO, 2008) and fertilizer N use in Ireland has fallen by 30% in the last decade due to a number of factors (Humphreys, 2008), the main one being the increasing cost relative to farm-gate product prices. Substantial reductions in fertilizer N use are evident in many countries in the European Union since 1990 (EFMA, 2005).

White clover-based swards have poor spring growth and poor yields of first-cut silage. Further, persistence of clover is variable causing inconsistent production from year to year compared to fertilizer-N-based grassland (Frame and Newbould, 1986). As an early turnout to pasture in spring confers clear economic advantages (Sayers and Mayne, 2001; Dillon *et al*., 2002; Kennedy *et al*., 2005) the necessity to delay turnout date would be a serious impediment to the adoption of white clover-based grassland on Irish farms. To solve the first two problems outlined above, in Humphreys *et al*. (2008) and in the experiment reported here, fertilizer N was applied to the clover-based swards in spring (until mid-April) for early spring herbage production and for first-cut silage production. Fertilizer N can be applied in spring at rates of 50 to 70 kg/ha to give improved production in spring without affecting annual production of clover-based swards (Laidlaw, 1980), although it can cause a lower clover content in swards later in the growing season (Frame and Boyd, 1987).

Regarding variability in clover persistence, as an insurance against clover die-out Humphreys *et al*. (2008) have successfully demonstrated in a full scale production system that clover can be introduced and established by over-seeding into grass silage stubble. They have also shown that clover concentration can be maintained by a programme of over-seeding of about one fifth of the area each year, securing consistent contribution of clover from year to year.

To evaluate the milk production potential of a grass/white clover system in which the components of spring-applied nitrogen fertilizer and a routine of over-seeding with clover were incorporated, the system was compared to a fertilizer-N-based grassland system over four years. The present paper examines herbage production, nutritive value of herbage, length of the grazing season and milk production per cow and per ha from the two systems. Results from the grass/clover system are compared with data from similar experiments conducted in temperate regions of the world. The results of environmental measurements will be reported elsewhere.

In contrast to the study of Ryan (1986; 1989) in which cows with low genetic potential for milk production, by present day standards, were stocked at a high rate and grazed a relatively short season (mid-April to late October), in this study spring-calving cows with higher genetic potential grazed over a long grazing season (early February to late November) and produced most of their milk while at pasture.

Materials and Methods

Site Characteristics, grass growth and weather conditions

This experiment was conducted at the Teagasc Solohead Dairy Research Farm (lat 52°51′N; 8°21′W; altitude 95 m above sea level). The soil had clay loam soil texture (Anon., 1951); 25% sand and 42% clay in the upper 20 cm of the soil. The topography of the site was relatively flat. Drainage was impeded, contributing to waterlogged conditions under high rainfall. Weekly grass growth data was measured on plots (CF-plots) adjacent to the main experiment using the methodology described by Corrall and Fenlon (1978), with overlapping harvests at four-week intervals throughout the entire growing season replicated five times. Annual fertilizer N input was 300 kg/ha. Meteorological data were recorded at the climatological station located on the research farm as described by Fitzgerald and Fitzgerald (2004). Soil moisture deficits (SMD) during the experimental period were calculated using the model developed by Schulte *et al*. (2005).

Experimental layout and design

There were two systems of grassland-based milk production, both stocked with spring-calving Holstein-Friesian dairy cows. The grassland area had previously been sectioned into five blocks depending on soil type and drainage status as described by Humphreys *et al*. (2008). The area used in this experiment was 22 ha: 11 ha of clover-based swards and 11 ha of predominantly perennial ryegrass swards. These clover-based and grass swards were previously used in the experiment described by Humphreys *et al*. (2008). The white clover-based swards were established between 1999 and 2002, received annual input of 80 kg/ha of fertilizer N between 2000 and 2002, and had an average clover concentration of herbage DM of 240 g kg^{-1} in 2001 and 2002. The grass swards received approximate annual fertilizer N inputs of either 250 or 350 kg/ha between 2000 and 2002 and the clover concentration of these swards was <50 g kg^{-1} DM during these three years.

In the present experiment, average annual fertilizer N input to the clover-based system (WC) was 90 kg/ha (annual range 84–99). Approximately 0.2 of the area of this treatment was over-seeded with white clover seed each year to maintain the clover concentrations of swards. This involved broadcasting 5 kg/ha of clover seed (equal proportions by weight of cultivars Aran and Avoca) with fertilizer (containing P at 0.07 g/g and K at 0.30 g/g) onto silage stubble after first-cut silage in late May. The fertilizer-N-based grassland system (FN) received an average annual input of 226 kg/ha of fertilizer N (annual range 219–240). In both systems fertilizer N refers to urea (N concentration 0.46 g/g) applied until the end of April each year and calcium ammonium nitrate (N concentration 0.275 g/g) applied between early May and mid-September. These were the only forms of synthetic fertilizer N used in this study.

Stocking density of dairy cows was the same on both systems: 2.0/ha in 2003 and 2.2/ha in each of the following three years. There were 22 cows per treatment in 2003 and 24 per treatment in each of the following three years. Each spring, cows were divided into four main groups on the basis of lactation number (1, 2, 3 & ≥4) and then sub-divided into sub-groups of two on the basis of calving date. From within each sub-group one cow was randomly assigned to each herd. The same procedure was followed each spring. Herds were randomly assigned to system each spring. Cows calved between late January and late April each year and the mean calving dates were 27 February in 2003, 27 February 2004, 17 February 2005 and 16 February 2006. The length of the lactation was from the commencement of calving in late January until the third week of December in each year.

Table 1. Target proportion of the area closed for silage, patterns of application of fertilizer N to the grazing and silage areas of two grassland-based systems of milk production stocked at the same density

	Grassland system	
	WC	FN
Target proportion of area closed for silage		
First-cut silage	0.50	0.50
Second-cut silage	0.15	0.15
Fertilizer N applied to the grazing area (kg/ha)		
February		28
March	28	28
April	28	57
May		34
June/July		34
August		17
September		17
Total applied to the grazing area	56	215
Fertilizer N applied to the silage area (kg/ha)		
Early grazing on silage area	28	28
First-cut silage	85	85
Second-cut silage	0	85
Total N input (kg/ha)	90	226

Application of fertilizer N and slurry management

The patterns of application of fertilizer N for each system are presented in Table 1. Fertilizer N was applied for early grazing on the silage areas during late February or early March. The entire area was grazed between turn-out and early April. Fertilizer N for the area providing first-cut silage was applied in early April in both systems. Fertilizer N for the area providing second-cut silage was applied in early June to the FN system but not the WC system. After first-cut silage in late May or early June and after second-cut silage in mid- to late-July the silage areas were subsequently used for grazing and received similar inputs of fertilizer N to that applied to the grazing areas of each system (Table 2).

Cows were housed during the winter and fed together as one group. All of the slurry produced was contained in a single storage tank. Equal volumes of slurry were applied back to each system based

Table 2. Dates of turnout of calved cows in spring and housing for the winter, additional days housed during the main grazing season (to avoid excessive damage to the sward) and total days grazing

	Year × Grassland system‡							
	2003		2004		2005		2006	
	WC	FN	WC	FN	WC	FN	WC	FN
Turnout date in spring								
Out by day	05 Feb	05 Feb	02 Feb	02 Feb	31 Jan	31 Jan	26 Jan	26 Jan
Out by day and night	14 Mar	14 Mar	20 Mar	20 Mar	18 Feb	18 Feb	28 Feb	28 Feb
Housing date for winter								
In by night	09 Nov	09 Nov	18 Nov	18 Nov	22 Oct	29 Oct	14 Nov	14 Nov
In by day and night	28 Nov	28 Nov	04 Dec	04 Dec	27 Nov	01 Dec	29 Nov	01 Dec
Additional days†	0.5	2.5	8.5	8.5	11.0	11.0	17.0	13.5
Total days outdoors†	255	253	254	254	250	256	251	255

† One day = out grazing day and night and one half day = out grazing by day only on two systems of grassland-based dairy production.
‡ See Table 1.

on calculated volumes of slurry produced per cow (DAFF, 1996). Slurry was applied in late January each year to approximately two-thirds of the area of each system. Slurry was also applied on the area for first-cut silage in late March and after harvests of silage. Slurry was applied using a downward-facing splash-plate.

Grazing management

Pasture was allocated to cows in a rotational grazing system and post-grazing heights, measured with a rising plate meter (Ashgrove Pastoral Products, Palmerston North, New Zealand), were used to determine when cows moved to the next section. Target post-grazing heights were 50 mm in February and March and allowed to rise progressively during the late spring and summer to 65 mm in July and August. Target post-grazing heights were 60 mm in autumn. Rotations were approximately 24 d in length during the main grazing season between April and September.

Milk production, live-weight and body condition score

Milk yield per cow was recorded at each milking and the composition of milk from each cow was measured for a successive morning and evening milking once per week using a Milkoscan 203 (Foss Electric DK-3400, Hillerød, Denmark). Solids-corrected milk yield was calculated using the equation of Tyrell and Reid (1965). The live weight of cows was recorded each week using a weighing scales and the Winweigh software package (Trutest Limited, Auckland, New Zealand). Body condition score (Lowman, Scott and Somerville, 1976) of each cow was recorded once fortnightly.

Length of the grazing season, sampling of herbage, herbage analyses and herbage production

The length of the grazing season was measured in terms of days at pasture where one day was defined as when all the cows per system were out day and night and one-half day when cows were out only by day. In spring when lactating cows were outdoors and cows yet to calve remained indoors, the proportion of cows outdoors per system was recorded. Likewise, when cows were being housed as they were dried off in the early winter the proportion of cows outdoors per system was recorded.

Herbage was sampled immediately before grazing within each system to get five samples of pre-grazing herbage per grazing rotation. Likewise, after each grazing, herbage was sampled adjacent to where the pre-grazing herbage was sampled. On each occasion four strips, each 5 m long and 0.55 m wide, were harvested per paddock using a Honda HRH-536 lawn-mower (Toss Bryan, Fermoy, Ireland) set at a cutting height of 40 mm above ground level. These were bulked and weighed to determine herbage mass. A sub-sample was dried for 16 h in an oven with forced-air circulation at 100 °C to determine DM concentration. A second sub-sample was taken and stored at −20 °C before being freeze dried and milled through a 0.2 mm sieve prior to chemical analyses for *in vitro* organic matter (OM) digestibility (Morgan, Stakelum and O'Dwyer, 1989). The N concentration in herbage DM was determined using a LECO 528 auto-analyser (LECO Corporation, St. Joseph, MI, USA) and multiplied by 6.25 to give the crude protein (CP) concentration in herbage DM.

Prior to harvesting herbage for silage, each silage paddock was divided into three sections. Within each section four strips (5.0 m × 1.1 m) of herbage were harvested using an Agria auto-scythe (Etesia UK Ltd., Warwick, UK). The herbage harvested within each section was bulked and weighed, and a sample taken for determination of DM concentration as described above. A second sub-sample was taken and analysed for *in vitro* OM digestibility and N concentration in herbage DM as described above. Silage intake for the entire herd was estimated during the winter-housing period as silage provided to cows minus rejected material. The net energy (NE) values of the herbage harvested for silage were related to the *in vitro* OM digestibility. The energy output in milk and energy required for maintenance and pregnancy were calculated using the methodology described by Humphreys *et al*. (2008). The NE concentration of the concentrate was calculated using the feed unit for lactation (UFL) concentration of the ingredients (O'Mara, 1996). The NE concentration of pasture was related to its chemical composition (Jarrige, 1989). Intake of grazed pasture DM by the cows was calculated by the difference between NE intake from silage and concentrate DM and that needed to meet the NE requirements for milk production, maintenance and body weight change (Jarrige, 1989).

The proportion of white clover in herbage

The proportion of white clover in the herbage of each paddock was determined during April and August each year. At twenty-five locations, randomly selected within each paddock, a strip of pasture 100 mm wide × 150 mm long was cut at a height of 50 mm above ground level using a hand shears. All of the harvested pasture was collected and bulked for each paddock. The white clover herbage in each bulked sample was separated from the remainder of the herbage which mostly consisted of perennial ryegrass and both the white clover and the remaining herbage were dried at 100 °C for 16 h to determine the clover content of swards on a DM basis.

Statistical analyses

Animal production data (milk production, milk composition, live-weight and body condition score) were subjected to ANOVA. Milk yields and yields of fat, protein and lactose in the third week of lactation were used as covariates for the analysis of total milk yields and yields of fat, protein and lactose. Pre-calving live weight and body condition score were used as covariates when analysing live weight and body condition score during and at the end of lactation.

Measurements of herbage from the grazing area in both systems were conducted on five occasions (replications) per rotation, with eight rotations per year over each of four years. Rotation was included as repeated measures effect in the ANOVA. The *in vitro* OM digestibility and CP concentration in pre-grazing herbage were analysed as a three factor (system × sampling date × year) ANOVA examining the main effects of each factor and all interactions between factors, with five replicates.

Characteristics of the herbage harvested for silage (*in vitro* OM digestibility and N concentration in silage DM) were subjected to ANOVA that included system, year, paddock from which the herbage was harvested as a split-plot, with three replicates. The main effects of system and year, and their interactions were examined.

Results

The length of the grazing season, weather conditions and concentrates fed to cows

Lactating cows were turned out to pasture by day from late January or early February each year depending on pasture supply and the suitability of ground conditions for grazing (Table 2). On average, cows spent 254 days at pasture. There was no ($P > 0.05$) difference in the length of the grazing season between the two grassland systems (s.e. 0.9) and the differences among years were minor. Occasionally cows were housed by night during the main grazing season due to very wet weather conditions and to avoid excessive damage to the soil surface. For example, exceptionally wet conditions during May 2006 (Figure 1b,c) meant that cows had to be housed on 15 consecutive nights during that period. Although May 2006 had exceptionally high rainfall, very dry soil conditions were experienced during late June, July and August, leading to lower pasture production during July and August that year compared with the previous three years (Figure 1d). Average annual rainfall (mm) was 845, 1000, 885, 1120 for each of the four years (2003–2006), respectively, compared with a 10-year average of 1005 mm at Solohead Research Farm. Despite an exceptionally dry summer, annual rainfall in 2006 (1120 mm) was above average. There was a ($P < 0.05$) interaction between system and year for the quantity of concentrate DM fed to cows; while there was no differences in the quantities of concentrates fed to cows in the two systems in each of the three years, 2003, 2004 and 2005, a greater ($P < 0.05$) quantity was fed to cows on WC than FN in 2006 (Table 3).

Milk production, body weight and body condition score

There were no differences in annual milk production per cow (mean (s.e.) 6524 (83.9) kg) between systems. Likewise, there were no differences between systems in annual production per cow for solids corrected milk (6422 (71.6) kg), milk fat (273 (3.2) kg), milk protein (233 (2.7) kg), lactose (309 (3.9) kg) or for calving date (22 February (0.83) days), lactation length (286 (1.5) days), body weight during the experiment (595 (4.4) kg), body condition score during the experiment (2.98 (0.022) units) or body condition score at the end of lactation (2.92 (0.027) units). Furthermore there were no differences between years or interactions between system and year for any of the above variables.

Herbage production and the nutritive value of herbage

Annual yields of herbage DM were higher ($P < 0.01$) on FN than WC (Table 3). Annual herbage production on the CF-

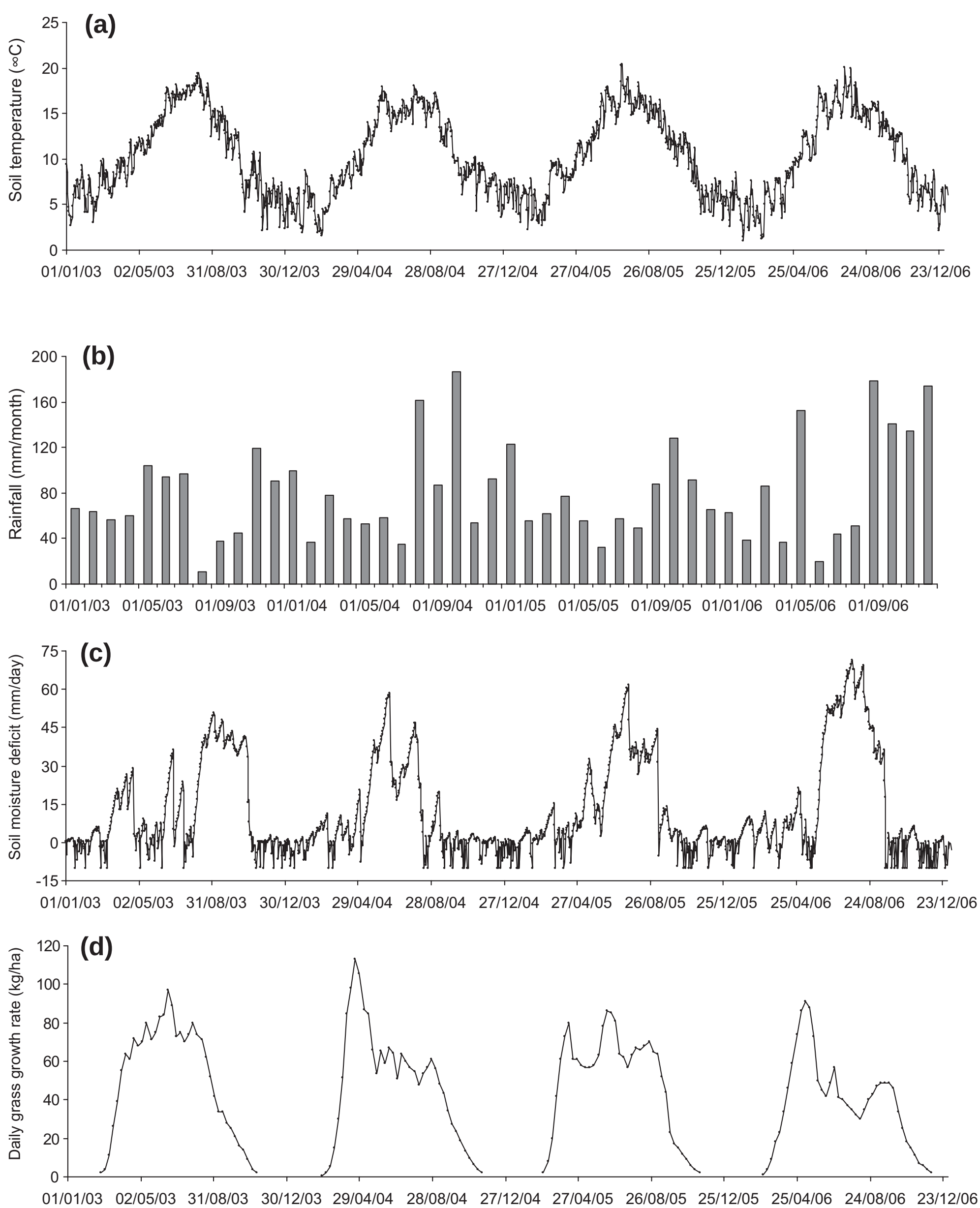

Figure 1. Soil temperature at 100 mm depth in soil (a), monthly rainfall (b), soil moisture deficits (c) and daily grass growth rates measured using the methodology of Corral and Fenlon (1978) (d) between 1 January 2003 and 31 December 2006 at the experimental site.

plots were (t/ha): 13.4, 12.9, 13.0 and 10.7 in each of the four years 2003 to 2006, respectively. Lowest yields were recorded in 2006, similar to the grassland systems experiment. Annual herbage production from FN was 0.96, 0.97, 0.99 and 1.08 of the herbage yields measured on the CF-plots in each of the four years. Annual herbage production from WC was 0.89, 0.92, 0.92 and 0.95 of the CF-plots. Annual yields of clover herbage DM were higher ($P < 0.01$) on WC than FN (Table 3). The average annual proportion of clover in total herbage DM was 219 g/kg on WC compared with 60 g/kg on FN.

In general, pre-grazing mass of herbage DM was higher ($P < 0.001$) on FG than WC (1835 versus 1646 kg/ha; s.e. 31.2 kg/ha), although this was influenced by an interaction ($P < 0.05$) with sampling date and year. There was little difference between systems in 2003 and the greatest difference was recorded in 2006. Pre-grazing herbage mass varied with sampling date but followed no particular trend during the experiment. There was no difference in post-grazing herbage DM mass between systems (FG, 506 and WC, 494 kg/ha; s.e. 18.6 kg/ha) and there were no interactions with sampling date, year or sampling date and year. Post-grazing mass was influenced by a ($P < 0.01$) interaction between sampling date and year. Lowest post-grazing masses were recorded in spring and autumn and highest in late summer in line with the target post-grazing heights imposed.

The *in vitro* OM digestibility of pre-grazing herbage was not significantly influenced by the grassland system (Figure 2a) and there were no interactions with sampling date, year or sampling date and year. There was a ($P < 0.001$) interaction between sampling date and year. Lowest digestibilities were generally recorded between July and September (s.e.m. 8.1; Figure 2). The CP concentration in pre-grazing herbage DM was higher ($P < 0.001$) on FN than WC: 219 and 209 g/kg, respectively (s.e. 8.4), and this was not influenced by interactions with sampling date, year or sampling date and year (Figure 2b). The CP concentration in pre-grazing herbage DM was influenced by an interaction ($P < 0.001$) between sampling date and year. Highest concentrations were generally recoded in spring and autumn and lowest in summer.

Consistently greater ($P < 0.01$) quantities of herbage were harvested for silage from FN than from WC each year (Table 3).

Table 3. Concentrates dry matter (DM) fed to cows, annual herbage and clover DM production, herbage DM harvested for silage, *in vitro* organic matter (OM) digestibility and crude protein concentrations in herbage DM harvested for silage during four years in two systems of grassland-based dairy production

	Year × Grassland system[†]		s.e.	Significance
	WC	FN		
Total concentrate DM fed per cow (kg)	531	520	5.1	
Total herbage DM production (kg/ha)	11507	12453	105.8	**
Clover herbage DM production (kg/ha)	2515	753	130.9	**
Herbage harvested for silage				
Herbage DM harvested per cow (kg)	1875	2308	42.1	**
In vitro OM digestibility (g/kg)	788	781	3.4	
Crude protein concentration (g/kg DM)	161	160	3.7	

[†] See Table 1.

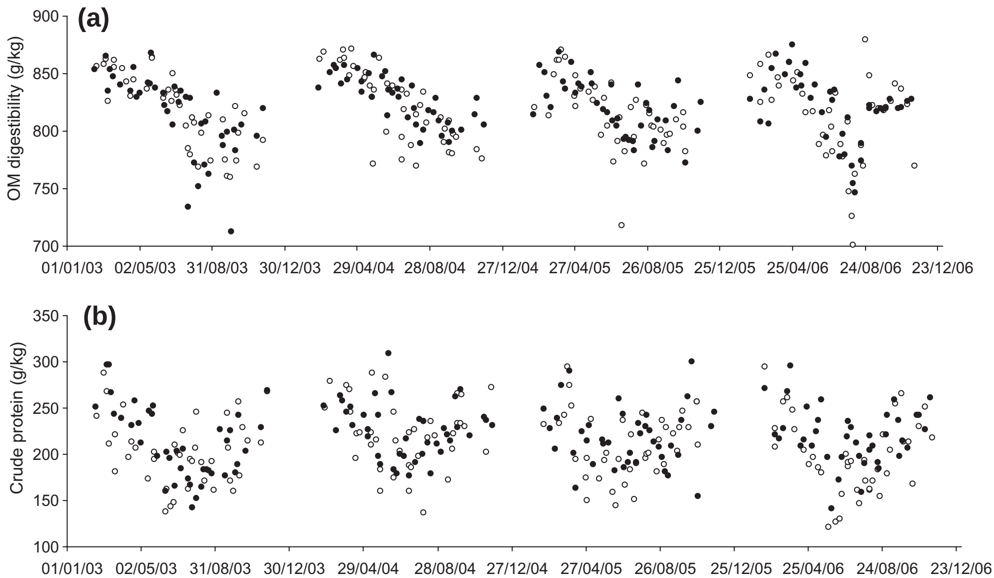

Figure 2. The in vitro organic matter (OM) digestibility of pre-grazing herbage (a) and the crude protein concentrations in pre-grazing herbage (b) throughout four years in two systems of grassland-based dairy production (WC – clover-based system, annual fertilizer N input of 90 kg/ha [○] and FN – fertilized grass-based system, annual fertilizer N input of 226 kg/ha [●]). Means of five replicates.

The *in vitro* OM digestibility of herbage and the CP concentration in herbage DM harvested for silage were not different between the systems, nor were there interactions between system and year (Table 3).

Discussion

Grass growth, weather conditions, concentrates and silage fed to cows

The CF-plots received 300 kg N ha^{-1} annually compared with 226 kg N/ha for FN. However, considerable quantities of N were recycled in excreta each year on FN either by the grazing cows or as slurry and dirty water, which explains the similarity in herbage yields in the FN system and the CF-plots. Highest annual DM yields on the CF-plots were recorded in 2003 and there was little difference in annual herbage DM yields between 2004 and 2005. Annual herbage production during 2006 in CF, FN and WC was substantially lower than these earlier years (Figure 1d) mainly due to low rainfall and high SMD between late June and late August 2006 (Figure 1b,c) and explained the higher quantity of concentrates fed in both systems and lower amounts of silage made, especially in WC, in 2006 (Table 3). Furthermore, fertilizer N input to both systems was higher in 2006 than preceding years but the length of the grazing season was no different from the other years (Table 2). This is partly due to the cows being supplemented with concentrates at pasture during the summer and partly by above average grass growth rate during the autumn and early winter 2006 (Figure 1d), which compensated, to a certain extent, for the poor pasture production during the summer. In 2003 a large surplus of silage was produced on both systems (stocked at 2.0 cows per ha). It was necessary to harvest 1635 (s.d. 30.4) kg herbage DM per cow to meet silage requirements, on average, over the four years. For each of the three years, 2004 to 2006, a surplus of herbage was harvested for silage on FN. There was also more than enough on WC in 2004 and 2005 but not in 2006. On the other hand, there was sufficient silage made on the WC system averaged over the four years.

Milk production per cow and sward nutritive value

There were no detectable differences in milk production per cow or milk composition between the grassland systems in this experiment. Most of the milk was produced while cows were at pasture. On average over the four years, grazed pasture accounted for 0.67, grass-silage 0.23, and concentrate 0.10 of the DM consumed by the dairy cows on both systems. This indicates that, although the swards on WC had substantially higher clover concentration in herbage DM than FN, this did not result in improved cow performance in terms of milk yield, milk composition, live weight or body condition score. This is in agreement with Humphreys *et al.* (2008) and similar systems-scale experiments in New Zealand, Germany, the Netherlands and Scotland (Table 4). In the experiments described in Table 4, there were generally no differences in milk output per cow from clover-based and fertilizer-N-based grassland. An exception was the second experiment (conducted in 1980/81) of Bryant, McDonald and Clayton (1982) where the length of lactation was curtailed by a shorter growing season on the clover-based system, which resulted in lower milk output per cow. The approach, where lactation length was determined by pasture availability, is also evident in the experiment described by Ledgard *et al.* (1998).

It has been shown that clover herbage has higher nutritive value than perennial ryegrass herbage (Wilman and Riley, 1993) and that intake of clover herbage by cows and milk production are higher than for perennial ryegrass (Thomson *et al.*, 1985). However, higher milk production from mixed white clover and perennial ryegrass swards is most evident when there is a high proportion of clover (>500 g kg^{-1} DM; Harris *et al.*, 1998) or where clover-based swards are compared with swards receiving no fertilizer N (Wilkins *et al.*, 1994; Phillips and James, 1998). In the experiment of Wilkins *et al.* (1994) white clover constituted 10, 150 and 200 g/kg of herbage OM in each of three swards. No fertilizer N was applied during the experiment (late April to early July) and CP concentrations in herbage DM were low on the low clover treatment and, in early July, fell to 74 g/kg compared with 110 g/kg on the high clover treatments. These CP concentrations are lower than the threshold value of 140 g/kg indicated by Peyraud *et al.* (2001) as being necessary to avoid negative impacts on herbage intake and milk yield of dairy cows. The higher herbage intakes and higher milk yields in the experiment of Wilkins *et al.* (1994) can be attributed to biological N fixation (BNF) associated with the higher clover concentrations contributing to higher CP concentrations in the herbage DM. In contrast, Ribeiro Filho, Delagarde and Peyraud (2005) described an experiment where fertilizer N was applied to perennial ryegrass and there was no difference in CP concentrations compared with white clover-based swards that received no fertilizer N but contained 270 g kg^{-1} clover in live herbage DM. Herbage digestibility, herbage intake and milk yield were higher on the

Table 4. The number of years that comparisons took place, stocking densities of dairy cows, annual fertilizer N input, concentrates fed to cows, annual herbage production and milk production in systems-scale comparisons of milk production from clover-based and N-fertilized grassland

Authors	No. of years	Stocking density (LU/ha)	Fertilizer N input (kg/ha)	Clover in herbage (g/kg DM)	Concentrates (kg) fed per		Herbage DM production (t/ha)	Milk Production per	
					Cow	Hectare		Cow (kg)	Hectare (t)
Bryant[1] *et al.* (1982)	1	3.86	0	270	211	815	16.25	3468	13.39
		3.86	86	270	211	815	16.11	3500	13.51
Bryant[1] *et al.* (1982)	1	4.09	0	230	245	1002	16.97	3196	13.07
		4.09	137	195	245	1002	18.08	3377	13.81
Weissbach and Ernst[2] (1994)	6	na[3]	0	150			na		8.56
		na	308	na			na		14.20
Ryan[4] (1986, 1989)	5	2.52	122	385	600	1512	na	4224	10.64
		3.20	361	<50	600	1920	na	4068	13.02
Ledgard[5] *et al.* (1998)	5	3.30	0	152	na	na	16.38	3953	12.96
		3.30	215	107	na	na	18.45	4735	15.52
		3.30	413	49	na	na	20.58	4858	15.92
Schils[6] *et al.* (2000)	3	1.90	17	290	1847	3509	10.10	8294	15.75
		2.20	208	<50	1828	4022	10.80	8095	17.80
Leach[7] *et al.* (2000)	1	1.90	0	253	1096	2082	9.24	5719	10.87
		2.40	350	9	1412	3389	10.35	5724	13.74
Humphreys[8] *et al.* (2008)	2	1.75	80	240	535	936	10.57	6550	11.46
		2.10	180	39	535	1124	10.75	6275	13.18
		2.50	248	20	535	1338	12.06	6242	15.61
		2.50	353	7	535	1338	13.26	6375	15.94
Present study	4	2.15	90	219	531	1142	11.51	6521	14.02
		2.15	226	60	520	1118	12.45	6526	14.03

(*Table 4 Continued*)

[1] Bryant, MacDonald and Clayton (1982) Calving in late winter and cows were milked at pasture. Lactation length was largely determined by pasture supply.
[2] There was no significant differences in concentrates fed per cow (4 kg cow^{-1} per day) or in milk production per cow (22.3 kg fat corrected milk per day).
[3] Data not available.
[4] Calving in late winter; grazing season from 9 April to 20 October. No fertilizer N was applied to the clover-based swards used for grazing; fertilizer N was applied to a non-clover silage area on the low fertilizer N input system. Clover concentration refers to the clover concentration of the clover-based swards in late summer only.
[5] Ledgard *et al*., 1998; Ledgard *et al*., 1999; Ledgard *et al*., 2001; Calving in late winter and cows were milked for 250 to 290 days at pasture. Minimal amounts of concentrate supplementation were fed to cows.
[6] Schils *et al*. (2000a), Schils *et al*. (2000b) Calving from October to April; grazing season from first week of April to last week of October.
[7] Leach *et al*., 2000; Bax and Thomas, 1992. Results from final year of a three year experiment. Autumn calving; cows dry during much of the grazing season, which extended from late spring to mid-October. Nine days later turnout in spring on the clover-based swards.
[8] Spring calving dairy cows managed in much the same way as the present experiment.

N-fertilized perennial ryegrass than on the clover-based swards. In an earlier experiment, Ribeiro Filho, Delagarde and Peyraud (2003) found that white clover-based swards with clover concentrations of, on average, 420 g kg^{-1} of live herbage DM increased herbage intake and milk yield of grazing dairy cows compared with N-fertilized perennial ryegrass swards. In the present experiment and in all the systems-scale experiments presented in Table 4, the clover concentration of herbage was not sufficiently high to show improved milk production from grazing dairy cows.

There were no differences in the *in vitro* OM digestibility of grazed swards between the systems, which partly accounts for the absence of a difference in cow performance in the present experiment. Cool temperatures in late spring and summer, which avoids high rates of lignification, and evenly distributed rainfall (Figure 1a,b) both support high digestibility of perennial ryegrass once there is adequate supply of nutrients, particularly N, in the soil (Deinum and Dirven, 1974). In the present experiment, lowest digestibilities (Figure 2a) tended to coincide with highest soil moisture deficits, most evident in the summer 2006 (Figure 1c). The CP concentration in pasture DM was lower on WC than FN; 209 versus 219 g/kg DM, which is a relatively small difference, and was lowest in June, July and August each year (Figure 2b). However, these lowest CP concentrations were not so low as to limit intake of pasture or milk yield of the grazing dairy cows (Peyraud *et al*., 2001; NRC, 2001).

There were no differences in the *in vitro* OM digestibility and N concentration in herbage DM harvested for silage; both systems received the same inputs of fertilizer N for first-cut silage (Table 1), which accounted for 0.72 of silage production on FN and 0.78 of silage production on WC (overall s.d. 0.155). There were also no differences in the N concentration in the concentrates fed to cows, which were common to both treatments. The main feed in winter was silage, supplemented in early and late lactation by concentrates. The N concentration of the winter diet was the same regardless of system and the same applies to the excreta produced during the indoor period. For these reasons, allocating the slurry to the two systems from a common pool was unlikely to have had important consequences for the quantities of N recycled back to each system.

Herbage production and soil N supply

Although there were substantial differences in fertilizer N inputs between the two systems, particularly in the seven month period between May and the end of the grazing season in late November, it is evident that BNF in the WC system was sufficient to support relatively high pasture production and N concentration in herbage DM during a large proportion of the grazing season. Most BNF takes place during the summer and autumn (Crush, 1987). In the present experiment milk production per cow on WC was the same as on FN but herbage production was proportionately 0.92 of FN, indicating that a higher stocking rate and milk output per hectare was possible from FN than WC. Schils *et al.* (2000a,b) in the Netherlands found that clover-based grassland receiving fertilizer N input of 17 kg/ha in spring produced 0.95 of the herbage of a perennial ryegrass sward receiving annual fertilizer N input of 208 kg/ha. Similar results were also found in New Zealand where clover-based swards receiving no fertilizer N produced herbage yields of 0.89 of swards receiving input of 215 kg/ha (Ledgard *et al*., 2001). This latter experiment was conducted at a site where lowest mean monthly soil temperature at 0.1 m depth was 7 to 8 °C in winter and peaked at approximately 20 °C in summer. In the present experiment the corresponding averages for the four years were 5.5 °C in winter and 16.6 °C in summer (Figure 1a). Average annual rainfall was approximately 1200 mm in the New Zealand study compared with 963 mm at Solohead. The annual range in soil temperatures in New Zealand was far more favourable for the growth of perennial ryegrass, white clover and BNF than in Ireland or Western Europe and this accounts for the higher herbage production per ha in New Zealand studies compared with the studies in Western Europe (Table 4). Higher stocking densities in New Zealand (Bryant *et al*., 1982; Ledgard *et al*., 1998) are related to pasture production as well as the genetic capacity of the cows for milk production. High milk production in some studies in Western Europe can be attributed to very high levels of concentrate supplementation per ha fed to cows with genetic capacity to give a milk production response to such diets (for example Schils *et al*., 2000b).

Herbage production per hectare provides a better comparison of the productivity of the grassland system than milk production per hectare because herbage production reflects soil N supply either from fertilizer N or BNF whereas milk production can also depend on large differences in concentrates fed per hectare. It is typically the case that concentrates are allocated on a per cow basis and thus, input per hectare increases with increasing stocking density. Davies and Hopkins (1996) reported that, under simulated grazing (frequent mechanical harvests and no returns of excreta) herbage production from clover-based grassland was similar to that from perennial ryegrass receiving fertilizer N input of 100 to 200 kg ha^{-1}. Higher values were associated with clover concentrations in swards of greater than 300 g kg^{-1} of herbage DM or on soils with a relatively poor supply of mineralized N. This range is in general agreement with the levels of relative productivity of the clover-based systems in Table 4. In the first experiment of Bryant *et al*. (1982) the application of 86 kg/ha of fertilizer N gave no increase in herbage or milk production per ha at the same concentrate input per ha. At a higher stocking density and fertilizer N input of 137 kg/ha in the second experiment, herbage and milk production was increased mainly through a longer grazing season and longer lactation length. This emphasizes the benefit of applying fertilizer N to clover-based swards in spring in terms of a longer grazing season and higher annual herbage production, although the clover concentration of swards decreased from 230 g/kg to 195 g/kg of herbage DM. In the experiment of Ledgard *et al*. (2001) input of 215 kg/ha of fertilizer N lowered the clover concentration of herbage DM from 152 g/kg to 107 g/kg, which makes it difficult to clearly assess the benefit of clover because it was contributing to both systems. In the experiment of Schils *et al*. (2000b) the clover concentration of the swards receiving fertilizer N input of 208 kg/ha was low, and on this basis, the clover-based swards were the equivalent of grass swards receiving fertilizer N input of approximately 180 kg/ha, under a mixed grazing and cutting system over a relatively short growing season. The clover-based swards in the experiment of Leach *et al*. (2000) showed high levels of productivity relative to grassland receiving very high input of fertilizer N, both stocked continuously during the grazing season. However, the grazing season was very short and the system of milk production was primarily based on harvesting herbage and feeding it indoors to autumn calving cows. Clover-based swards tend to be relatively more productive under cutting than grazing regimes because cutting tends to deplete soil N reserves, which increases BNF and the competitiveness of clover in the sward, whereas deposition of dung and urine and trampling by grazing livestock tend to reduce the clover content of swards (Frame and Newbould, 1986). Furthermore, increasing input of fertilizer N results in less efficient production of herbage DM per 1 kg of applied fertilizer N, as is evident from the results of Humphreys *et al*. (2008; Table 4). Hence, the value of clover can be best evaluated from N-fertilized swards with similar levels of productivity to the clover-based swards. In the study of Humphreys *et al*. (2008) and the present study the annual fertilizer N replacement value of white clover, in terms of herbage production, was approximately 98 kg/ha and 125 kg/ha in these two studies, respectively.

Statutory instruments No. 101, 2009 and milk production

Under SI No. 101 (2009) stocking densities on Irish grassland is limited to 2 dairy cows per hectare and, under these circumstances, fertilizer N input should not exceed approximately 200 kg/ha. The results of the present experiment shows that this stocking density is well within the carrying capacity of clover-based swards receiving 90 kg/ha of fertilizer N applied in spring for early spring grazing and for production of silage. At this stocking density, white clover can make a substantial contribution to lowering fertilizer N costs on farms. On more intensive grassland farms, there is the possibility of applying for a derogation from these limits. On derogation farms, which represent less than one third of all Irish dairy farms, maximum permissible fertilizer N input to grassland is approximately 275 kg/ha. The results of the present experiment and data presented in Table 4 suggest that the level of herbage production that can be achieved with this level of fertilizer N input is substantially higher than that achievable with clover-based swards, even with input of 80 or 90 kg/ha of fertilizer N in spring.

The clover content of swards and animal health

Clover swards or grass-clover swards with very high clover concentrations are sometimes associated with animal health problems such as bloat and hydrogen cyanide poisoning, particularly in New Zealand (for example, Johnson and Thomson, 1996). In the present experiment there were no incidences of problems with animal health that required treatment and no precautionary measures were taken to avoid bloat other than avoiding cows being very hungry when first allowed into swards with high clover concentration (>300 g/kg in herbage DM) in summer. Likewise, in the previous experiment (Humphreys *et al*., 2008) no cow on the clover-based system required treatment for clover-related disorders and no precautionary measures were necessary. This can be attributed to the relatively low clover concentration of herbage DM in both these experiments (Table 4).

The clover content of swards and over-seeding

The clover content of swards in the present experiment was marginally lower than the same clover swards used in the previous experiment (Table 4). Herbage production was generally higher in the present experiment except in 2006, for reasons outlined above. The average clover concentrations of herbage DM on the WC system were 239, 202, 225 and 206 g kg^{-1} DM in each of the four years of this experiment. There was no evidence of a crash in the clover content of swards in this or the previous experiment, except during the period of summer drought in 2006. However, this was of short duration and was followed by recovery of clover concentrations in the autumn. During the present experiment, swards with declining clover concentrations were identified, and around 0.2 of the area of the WC system was over-seeded with clover seed each year as described earlier. The establishment of these swards in the previous experiment and the maintenance of the clover content of swards in the present experiment were mainly due to over-seeding combined with low fertilizer N input. Over-seeding onto silage stubble in late May or early June on this heavy soil where soil moisture was rarely limiting (Figure 1c) contributed to maintaining the clover concentration of swards and consistent herbage production on the WC system during the four years of this study.

Conclusions

Well established white clover-based swards (WC) receiving annual fertilizer N input of 90 kg/ha applied for early grazing in spring and for first cut silage were able to support an annual stocking density of 2.15 cows per hectare, producing a milk output of 14 t/ha with an annual input of 531 kg concentrate DM per cow. Annual herbage production on WC was 0.92 (s.d. 0.029) of the FN treatment. There were no differences between systems in the length of the grazing season or the *in vitro* OM digestibility of the grazed pasture. The concentration of CP in herbage DM was higher on the FN system, although this difference was relatively small and did not impact on milk production per cow. The clover concentration in herbage DM of the WC system was greater than for the FN system but this had no effect on milk production, cow live weight and body condition score. Under the stocking rate limits imposed under SI No. 101 (2009) clover-based systems can support high levels of milk output with substantial savings in fertilizer N on non-derogation dairy farms.

Acknowledgements

Funding for this study was provided by the Irish National Development Plan and the Irish Dairy Levy. The authors acknowledge the technical input of A. Lawless and the farm staff at the Teagasc, Solohead Research Farm, and the staff at Moorepark Laboratories who conducted the analyses. Dr. E. Lewis and Dr. B. Horan, Teagasc, Moorepark DRPC provided critical comments on the manuscript.

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