The effect of applying cattle slurry within rotational grazing systems using trailing-shoe technology on dairy cow and sward performance

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STRUCTURE OF REPORT

This report begins with an Executive Summary which provides the background to the research, details of the work undertaken, key findings, and practical implications.

Chapter 1 of the report is a full scientific paper, which has been submitted to a scientific journal for publication.

The report finishes with a summary of the key presentations and publications completed during this project.

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EXECUTIVE SUMMARY

- Environmental regulations and the increasing cost of inorganic chemical fertilizers have encouraged farmers to consider the true nutrient value of animal manures. However, most slurry produced on Northern Ireland farms continues to be spread using the splash plate, a technique which results in high losses of nitrogen (N) through ammonia volatilisation at the time of spreading.

- Alternative slurry spreading techniques, such as trailing-shoe, band spreading, and shallow injection are increasingly available, and these have the potential to improve nutrient utilisation. For example, the trailing-shoe technique has been shown to increase grass dry matter yields by 26% when compared to the splash plate method.

- While silage fields have the largest requirement for slurry nutrients within a farm opportunities often exist to utilize slurry nutrients on 'grazing ground.' However, slurry applied using a splash plate can have a detrimental effect on the subsequent behaviour and performance of grazing animals, with these effects having been observed to persist for up to five weeks after application.

- Compared to the splash plate, alternative slurry spreading techniques will reduce contamination of the sward with slurry, and have been shown to have less impact on the behaviour of the grazing animal. However, previous work was mainly undertaken with dairy heifers or beef animals.

- The impact of using low emission slurry spreading techniques on the performance of lactating dairy cows had not been examined previously. Thus two experiments were conducted to examine the effect of applying slurry via the trailing-shoe technique on dairy cow and sward performance.

- <u>Experiment 1:</u> Two treatments were examined in an experiment involving forty-eight lactating dairy cows (Fertilizer only or Fertilizer plus slurry). The paddocks within the Fertilizer only treatment received only inorganic fertilizer nitrogen throughout the study (280 kg N/ha). With the Fertilizer plus slurry treatment, 80 kg

N/ha of inorganic fertiliser N was replaced with slurry (applied during the first and fourth rotation). Inorganic fertilizer nitrogen was applied after all other grazings (200 kg N/ha). The total available N supplied from the slurry applications (88 kg/ha) was a close match to the 80 kg/ha of fertilizer N replaced.

- Milk production and grazing behaviour: Replacing 80 kg N/ha of inorganic fertiliser N with slurry had no effect on average daily milk yield, milk fat and protein content and fat plus protein yield (Table A). Treatment had no effect on either body condition score or live weight at the end of the experiment. Treatment had no effects on any of the grazing behaviour parameters recorded during the fifth grazing rotation, a grazing cycle following slurry being applied.

Table A. Effect of source of applied nitrogen (Fertilizer only vs Fertilizer and slurry) on dairy cow performance in Experiment 1

	Treatment			
	Fertilizer only	**Fertilizer and slurry**	**s.e.m**	**Significance**
Daily milk yield (kg)	19.2	18.8	0.41	NS
Fat (g/kg)	42.2	42.1	0.68	NS
Protein (g/kg)	35.3	35.2	0.37	NS
Fat + protein yield (kg/day)	1.48	1.43	0.025	NS
Body condition score at end of experiment	2.3	2.3	0.09	NS
Live weight at end of experiment (kg)	531	532	11.6	NS

- Sward parameters: Average pre- and post-grazing sward heights with the Fertilizer only and Fertilizer plus slurry treatments in Experiment 1 were 10.1 and 10.5, and 5.7 and 5.9 cm, respectively. Similarly, overall mean utilization rates of available herbage (above 4 cm) were 73% and 71% for the Fertilizer only and Fertilizer plus slurry treatments, respectively.

- Results of Experiment 1 demonstrate that 80 kg inorganic nitrogen can be replaced with a similar quantity of available N from slurry without having a detrimental effect on animal or sward performance.

- Experiment 2: This experiment examined the use of slurry on grazing swards under more challenging conditions, namely when slurry was applied more frequently, and when cows were forced to graze tighter through the use of higher stocking rates.

- Four treatments were examined in a 2 x 2 factorial design experiment involving sixty dairy cows. Treatments comprised two stocking rates (High and Normal) and two nitrogen sources (Fertilizer only and Fertilizer plus slurry). The paddocks within the Fertilizer only treatments received inorganic fertilizer nitrogen only throughout the study (285 kg N/ha). With the Fertilizer plus slurry treatments, a total of 152 kg inorganic fertiliser N was replaced with slurry N, with slurry applied on four occasions throughout the grazing season. Due to a higher than expected ammonia N content within the slurry, the available N supplied from the four slurry applications (231 kg/ha) was higher than the 152 kg inorganic fertilizer N replaced.

- Milk production: Average daily milk yield was reduced with the higher stocking rate treatments and with the Fertilizer and slurry treatments (Table B). Source of nitrogen applied had no effect on milk fat or protein content or milk fat plus protein yield, while fat plus protein yield was reduced at the higher stocking rate. Treatment had no significant effect on either cow body condition score or live weight at the end of the study.

- Sward parameters: Average pre-grazing sward heights were 10.3 and 11.3 cm for the Fertilizer only and Fertilizer plus slurry treatment, respectively (high stocking rate) and 11.5 and 11.7 cm for these same two treatments at the normal stocking rate. The respective average post-grazing sward heights were 5.1, 5.4, 6.1, and 6.1 cm for these four treatments, respectively. Average utilization rates of available herbage (above 4 cm) at the high stocking rate were 83% and 81% (Fertilizer only and Fertilizer plus slurry treatments, respectively), compared to a utilisation efficiency of 73% with the normal stocking rate treatments.

Table B. Effect of stocking rate (High vs Normal) and source of applied nitrogen (Fertilizer only vs Fertilizer and slurry) on dairy cow performance

	Treatments				Significance		
	High stocking rate		Normal stocking rate				
	Fertilizer only	Fertilizer and slurry	Fertilizer only	Fertilizer and Slurry	s.e.d.	Nitrogen source	Stocking rate
Daily milk yield (kg)	19.1	17.6	20.2	19.6	0.63	*	**
Fat (g/kg)	42.7	43.7	42.2	41.8	1.18	NS	NS
Protein (g/kg)	34.0	34.6	34.9	34.6	0.58	NS	NS
Fat + protein yield (kg/day)	1.44	1.39	1.56	1.50	0.046	NS	**
Body condition score at end of experiment	2.6	2.4	2.7	2.6	0.10	NS	NS
Live weight at end of experiment (kg)	542	528	547	546	16.4	NS	NS

- Financial implications: The replacement of inorganic fertiliser N with slurry N in these two experiments will have resulted in savings in fertiliser costs, with the extent of this saving dependent on the cost of fertiliser. For example, the financial impact of replacing two applications of CAN (300 kg CAN/ha or 80 kg N/ha) with two applications of slurry (as in Experiment 1) are presented in Table C. For a 100 cow dairy herd, replacing 80 kg fertiliser N/ha with slurry during the grazing season could have resulted in a saving of up to £1,250.

- When a similar calculation is undertaken for Experiment 2, the net saving per 100 cows is £275, £1,100 and £1,950 at a CAN cost of £180, £240 and £300/t, respectively. This financial analysis was based on the fertiliser N saving alone. If there was an additional soil requirement for P and K, then the financial benefits would be increased.

Table C. The financial impact of replacing inorganic fertiliser N with slurry

	Fertiliser cost (£/t)		
	£180	£240	£300
Saving in cost of CAN (£/ha)	54	72	90
Extra charge for spreading slurry, less saving in fertiliser sowing charge (£/ha)[1]	-40	-40	-40
Net saving per hectare (£/ha)	14	32	50
Net saving per 100 cows (£)[2]	350	800	1,250

[1]*Slurry spreading charge of £25/hour, assuming a work rate of 6,000 gallons applied/hour*

[1]*Saving in fertiliser spreading cost (£10/ha) deducted from slurry spreading cost*

[2]*100 cow herd stocked at 4.0 cows/ha (Apr-Sept) = 25 hectares*

- <u>Other considerations:</u> Inorganic fertilizer inputs were reduced by 80 and 152 kg N/ha within the fertilizer and slurry treatments in Experiments 1 and 2, respectively, without having a detrimental effect on cow performance at a 'normal' stocking rate. However, when cows were forced to graze tighter, milk yield was reduced within the treatment involving slurry applications.

- Above average rainfall was recorded during June, July and August in both Experiments, and this may have helped wash slurry from the grass leaf down into the lower sward canopy, thus improving herbage palatability.

- Slurry should primarily be targeted at land areas where its full nutrient content, (including N, phosphate, and potash) is most required. Within grazing systems 'recycling' of these nutrients takes place via faeces and urine deposited by the grazing animal. Therefore caution is required when utilizing slurry within grazing paddocks, and it is important to ensure that there will be no detrimental effect on the nutrient balance of grazing areas, especially in relation to creating a 'phosphorus surplus.'

The effect of applying cattle slurry within rotational grazing systems using trailing-shoe technology on dairy cow and sward performance

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ABSTRACT

The effects of applying cattle slurry using the trailing-shoe technique on dairy cow and sward performances were examined in two experiments. In Experiment 1, 48 cows were allocated to two treatments: with or without slurry application. In Experiment 2, 60 cows were allocated to four treatments: a high and normal grazing stocking rate; and with or without slurry application. Slurry was applied during the first and fourth rotations in Experiment 1, and applied prior to the first grazing rotation, and during the second, fifth and sixth grazing rotations in Experiment 2. For Experiments 1 and 2 the total inorganic fertilizer nitrogen inputs applied within the slurry treatments were 200 and 133 kg ha^{-1}, with 280 and 285 kg ha^{-1} used within the fertilizer only treatments in each experiment, respectively. Milk yield and grazing behaviour were similar between treatments in Experiment 1. Following the application of slurry at the higher stocking rate in Experiment 2 average daily milk yield and total milk output were reduced. However, there was no effect on milk yield following slurry application at the normal stocking rate. Total inorganic fertilizer N replaced by slurry was 80 and 152 kg ha^{-1} in Experiment 1 and 2 respectively, indicating potential to improve the utilization of slurry nutrients.

Keywords: cattle slurry, trailing-shoe, dairy cows, rotational grazing

INTRODUCTION

The rapid intensification of livestock production systems during the last few decades resulted in manure frequently being viewed as a waste product, rather than as a valuable source of plant nutrients. However, as environmental regulations have become more restrictive and as the cost of inorganic chemical fertilizers have increased, farmers have become increasingly aware of the true value of animal manures. In addition, the EU

Nitrates Directive (EEC/91/676) has also had an impact on how farmers view slurry. For example, when a country or region is designated a Nitrate Vulnerable Zone under the Directive, an action programme must be implemented, and this will normally include the introduction of a closed period during which slurry cannot be spread. Within Northern Ireland the Nitrates Directive Action programme (DARD, 2006) prevents the spreading of slurry during the period between 15 October and 31 January. As a consequence, livestock farmers now enter the spring with significant quantities of slurry in storage tanks. As many farmers have invested heavily in slurry storage capacity to meet the requirements of these action programmes, it makes economic sense to recoup some of this outlay by maximizing the efficiency with which nutrients within slurry are utilized.

However, it is widely accepted that there can be significant loss of nitrogen via ammonia volatilization during slurry application to the land, especially when slurry is applied using splash plate techniques (Frost *et al.,* 1990; Luxen, 1994; Chambers *et al.,* 2000; Misselbrook *et al.,* 2000; Saggar *et al.,* 2004). Alternative slurry spreading techniques are now widely available (Frost, 1994; Misselbrook *et al.,* 1996; 2002; Smith *et al.,* 2000; Binnie and Frost, 2003; Schils and Kok, 2003; Lalor and Schulte, 2008), and these have the potential to reduce nutrient losses associated with the conventional splash plate method of application (where slurry is deposited across the whole surface of the grass canopy). These include shallow injection, trailing-shoe and band spreading (where slurry is deposited in narrow slots in the soil, in bands on the soil surface under the grass canopy or in bands above the grass canopy, respectively). Indeed, recent research has demonstrated that nitrogen losses can be reduced by approximately 10 or 25% when slurry is applied using either band spreading or trailing-shoe type systems, respectively, rather than via a splash plate, and grass dry matter (DM) yield increased by 18% and 26%, respectively

(Frost *et al.*, 2007). While the injection of slurries is most effective on flat, stone free land, the trailing-shoe technique is not influenced to the same extent by land type and aspect and as such, has the potential to be widely used in grass growing regions of Europe. In addition, compared to band spreading, the trailing-shoe has particular benefits in that slurry is placed at the base of the sward thus minimizing contamination of the grass leaves with slurry.

As large quantities of nutrients are removed from fields when silage is harvested, it makes good management sense to return these nutrients by prioritising slurry applications to silage fields (MAFF, 2000). However, with increased quantities of slurry stored on farms in the spring as a result of closed periods, there may be opportunities to make effective use of some slurry on grazing areas. Nevertheless, applying slurry to grazing land using the splash plate technique has been shown to have an adverse effect on the grazing behaviour of dairy heifers (Pain *et al.*, 1974) and dairy cows (Pain and Broom, 1978). In addition, milk yield and liveweight gain were reduced when animals grazed pastures after slurry had been applied using a splash plate, with these effects persisting for at least five weeks after slurry application (Danby *et al.*, 1997a). More recent studies have demonstrated that adverse effects on the performance of beef cattle and dairy heifers were reduced when slurry was spread using shallow injection and trailing-shoe techniques, compared to splash plate spreading (Laws *et al.*, 1996; Laws and Pain, 2000; 2002). However, little work appears to have been undertaken to examine the effects of using low emission slurry spreading techniques on the performance of lactating dairy cows. Thus two experiments were conducted to examine the effect of applying slurry via a trailing-shoe on dairy cow and sward performance.

MATERIALS AND METHODS

The two experiments presented within this paper were conducted at the Agri-Food and Biosciences Institute, Hillsborough (54^{o}27'N; 06^{o}04'W), with cows grazing predominantly perennial ryegrass (*Lolium perenne)* swards located on a free-draining, heavy loam soil.

Animals and treatments

Experiment 1 involved 48 lactating dairy cows (17 primiparous and 31 multiparous) of mixed genotypes (27 Holstein-Friesian (H), 8 Norwegian Red (N), 4 crossbred cows (H x N) and 9 Jersey x H). Cows had a mean calving date of 31 January (s.d. 38 d), and a mean pre-experimental live weight and milk yield of 514 (s.d. 76) kg and 27.7 (s.d. 6.8) kg d^{-1}, respectively. Experiment 1 was a continuous design experiment involving two treatments, fertilizer only and fertilizer and slurry.

Experiment 2 involved 60 lactating dairy cows (12 primiparous, 48 multiparous), of mixed genotypes (25 H, 12 N and 23 H x N). Cows had a mean calving date of 5 February (s.d. 29 d) and a mean pre-experimental live weight and milk yield of 528 (s.d. 55) kg and 27.7 (s.d. 4.9) kg d^{-1}, respectively. Experiment 2 involved a continuous 2 x 2 factorial design experiment comprising two stocking rates (high and normal) and two nitrogen sources (fertilizer only or fertilizer and slurry). Full details of the experimental treatments are provided later.

Post-calving and prior to the start of the grazing period, the cows used in Experiments 1 and 2 were offered grass silage, supplemented with either 5.0 (primiparous) or 7.0 (multiparous) kg d^{-1} of concentrates through the parlour, split between two equal feeds. Animals were housed as a single group throughout this pre-experimental period. Cows were allocated to their treatment groups at the start of each experiment, with groups balanced for pre-experimental milk yield, milk fat and milk protein concentration, live weight and body condition score, parity, calving date and genotype.

Grazing management

Within Experiment 1 cows initially commenced grazing on 31 March (as a single group), and achieved full time grazing by 8 April. Animals continued to graze as a single group until the study commenced (28 April). Concentrate feed levels were reduced to 4.0 kg cow^{-1} d^{-1} during the week prior to the start of the study, and to 3.0 kg cow^{-1} d^{-1} on 7 May. Concentrate feed levels were further reduced to 2.0 kg cow^{-1} d^{-1} on 22 July, with this feed level maintained until the end of the study.

Prior to the start of Experiment 2 cows commenced grazing on 26 March (initially for 2 to 3 hours daily as a single group) with the grazing period being extended so that cows grazed by both day and night by 16 April. Cows continued to graze as a single group until the experiment commenced (30 April). Concentrate feed levels were reduced to 3.0 kg cow^{-1} d^{-1} a week prior to the start of the experiment, and further reduced to 2.0 kg cow^{-1} d^{-1} on 5 May. However, a prolonged period of wet weather necessitated concentrate feed levels being increased to 4.0 kg cow^{-1} d^{-1} on 16 July, remaining at this level until the end of the study.

Commercial concentrate feedstuffs were offered in each of Experiments 1 and 2, with the main non-mineral ingredients being maize meal, wheat, rapeseed extract, soya hulls, wheat feed, palm kernel expeller, soya, molasses, and palm oil blend in Experiment 1, and maize meal, wheat, rapeseed extract, soya hulls, distillers grains, maize gluten, wheat feed, palm kernel expeller, soya, molasses and palm oil blend in Experiment 2.

Both experiments involved rotational paddock grazing systems, with fresh herbage offered daily after evening milking. Prior to the start of each experiment, 24 1-d paddocks were established for each treatment (total of 48 and 96 paddocks in Experiments 1 and 2, respectively). The paddocks were established across the grazing area and allocated to treatments taking account of field topography and soil type. Each paddock was 0.2 hectares (ha) for both treatments in Experiment 1, and 0.124 and 0.103 ha for the normal and high stocking rate treatments in Experiment 2. In order to maintain grass supply as the season progressed, additional paddocks were introduced (equal numbers to each treatment) into the grazing rotation in both experiments. Prior to being introduced these additional paddocks were grazed by non-experimental animals or cut for silage to ensure they were at the correct growth stage when required. Due to a period of rapid grass growth in late April and early May in Experiment 2, only 14 paddocks were grazed by the experimental animals during the first rotation, with the remaining paddocks predominantly cut for silage (4 May) or grazed with non-experimental animals. Grazing rotation length was adjusted depending on grass supply within the fertilizer only treatment in Experiment 1 and the normal stocking rate fertilizer only treatment in Experiment 2.

All paddocks were topped using a disc mower to a height of approximately 4.0 cm during the fourth grazing rotation in Experiment 1. Cows remained on the study until 24 September (150 d), having completed six full grazing rotations (20, 24, 24, 22, 26, 26 and 8 d). The final grazing rotation was restricted to eight days due to poor ground conditions and insufficient grass supply. During the fifth and sixth grazing rotations in Experiment 1, wet conditions resulted in the housing of animals for a total of nine 24-h periods. While housed, cows were offered grass silage mixed with 2.0 kg citrus pulp cow^{-1} d^{-1} as a mixed ration, in addition to their normal daily parlour concentrate allowance.

Within Experiment 2 all paddocks were topped using a disc mower to a height of approximately 4.0 cm during the third grazing rotation. Cows remained on the study until 7 October (161 d) having completed seven grazing rotations (14, 25, 21, 26, 28, 26 and 21 d in length), with all treatments following the same rotation length, within each grazing rotation (Table 1). During the fourth and fifth grazing rotations wet conditions resulted in cows being housed for a total of nine 24-h periods. During these housed periods cows were offered grass silage mixed with 2.0 kg concentrate cow^{-1} d^{-1} as a mixed ration, in addition to their normal daily parlour concentrate allowance.

Fertilizer and slurry management

Within the fertilizer only treatments in Experiments 1 and 2, the total input of inorganic N during the grazing season was 280 and 285 kg ha^{-1}, respectively (Table 2). This was applied pre-turnout (28 kg N ha^{-1} as urea (proportionally 0.46 N) during late February and mid March in Experiments 1 and 2, respectively), post the first non-experimental rotation (60 kg N ha^{-1} as calcium ammonium nitrate (proportionally 0.27 N)), and post each of the first to sixth experimental rotations (as calcium ammonium nitrate). No fertilizer or slurry was applied after the seventh (and final) experimental rotation (Table 2). Inorganic fertilizer was weighed out for each individual paddock prior to being applied using a tractor mounted fertilizer distributor (Vicon, PS503; Kverneland Group Ltd, St Helens). Slurry was applied during the first and fourth grazing rotations in Experiment 1, and during the first non-experimental rotation, the second, fifth and sixth grazing rotations in

Experiment 2. No inorganic fertilizer N was applied during the rotations when slurry was applied. In order to limit the number of occasions when slurry was applied during any grazing rotation it was planned that slurry would be normally applied to paddocks 1-10 immediately after the tenth paddock had been grazed, and to the remaining paddocks within the grazing rotation after the final paddock had been grazed, thus giving a target minimum interval between slurry application and the next grazing of ten days. In practise the average interval between slurry application and grazing in Experiment 1 was 6 and 4 d (interval reduced because slurry applications were delayed due to adverse weather conditions) with the equivalent interval following the slurry applications within the four grazing rotations in Experiment 2 being 13, 12, 19 (interval extended due to three days of housing) and 17 d. During rotations when slurry was applied, fertilizer applications were delayed within the fertilizer only treatments to match the block applications of slurry. While it was accepted that this did not reflect what would be done in practice, this was adopted to ensure that nutrients applied within both treatments were exposed to the same weather conditions during the post-application period, when nutrient losses can be high. On all other occasions fertilizer was normally applied within 3-4 d of each paddock having been grazed. Due to trafficability problems (soft ground as a result of high rainfall), slurry was not applied to eight paddocks during the fifth rotation, and to a further three paddocks during the sixth rotation within Experiment 2. These planned slurry applications were replaced by inorganic fertilizer N.

All slurry was applied using a 9 m^3 vacuum tanker (Abbey Farm Equipment, County Tipperary, Ireland) fitted with a 6 m wide trailing-shoe applicator (containing 24 shoes, spaced 260 mm apart). Target slurry application rates were designed so that the quantities of available N (ammonia N) applied via slurry was equal to the quantity of total N applied from inorganic N. Within each slurry application available N was calculated assuming slurry to have a total N content of 3.5 kg $m^{3\ -1}$ fresh and an available N content of 1.4 kg $m^{3\ -1}$ (proportionally 0.4 available) (Frost *et al.*, 2007). The vacuum tanker was fitted with an electronic flow meter that allowed the operator to monitor the application rate and adjust tractor forward speed to ensure the correct volumes of slurry were applied. Actual quantities of available N applied were subsequently determined based on the actual chemical composition of the slurry applied.

Measurements

Sward and slurry measurements

Pre- and post-grazing sward heights were measured daily using a rising plate meter (Jenquip, New Zealand) taking 40 and 20 measurements per paddock within Experiments 1 and 2, respectively. Across all treatments in both experiments a sample of the herbage within the paddocks was taken pre-grazing weekly, and analyzed for water soluble carbohydrates (WSC), acid detergent fibre (ADF), metabolizable energy (ME) and crude protein (CP). The samples were analyzed fresh by near infrared reflectance spectroscopy (NIRS), using the methodology and equipment as described by Park *et al.* (1999) for conserved grass silage, but using a calibration equation developed for fresh grass. These samples were cut with battery operated clippers (Gardena Accu 6, Kress and Kastner, Weiterstadt, Germany), and taken from areas and to a depth within the sward representative of herbage being grazed by the animals.

On each occasion when slurry was applied within Experiments 1 (n=5) and 2 (n=12) the slurry tanker was weighed both empty and full over a 100,000 kg weighbridge (accuracy ±10.0 kg), and the actual quantity of slurry applied calculated. On each occasion when slurry was applied, a sub-sample of slurry being applied was collected and subsequently analyzed for oven DM, total N and ammonia N contents and pH as described by Frost *et al.* (1990). A weighted mean composition of the slurry applied within each grazing rotation was then calculated reflecting the number of paddocks to which slurry was applied on each occasion.

Measurements on dairy cows

Throughout Experiments 1 and 2, cows were milked twice daily, between 06.30 and 08.30 hours, and between 16.00 and 18.00 hours, with milk yields recorded at each milking. During two successive milkings each week, a milk sample was collected from each cow and analyzed for fat, protein and lactose concentrations using an infrared milk analyzer (Milkoscan Model 605; Foss Electric, Warrington, UK), and a weighted milk composition for the 24-h period calculated. Milk energy concentration was determined using the equation of Tyrell and Reid (1965). Cow live weight and body condition score were recorded prior to the start of, and at the end of each experiment.

During four consecutive 24-h periods (4 to 8 August) in Experiment 1, the temporal grazing pattern of 10 Holstein-Friesian cows (5 from each treatment) was examined using grazing behaviour recorders (Gibb *et al.*, 1997). The cows selected from within each treatment were balanced for parity, milk yield, days in milk, live weight and body condition score. This measurement period was during the fifth grazing rotation, an average of 5 days following the application of slurry. Recorders were fitted after evening milking, and removed prior to evening milking the following day. This allowed time for data to be down-loaded and batteries replaced, before being again refitted to the same cow post evening milking. Time spent grazing and ruminating, total bites taken and total boli produced were measured. In calculating grazing time, it was assumed that the cows were grazing only after they grazed for periods longer than 5 minutes (Rook and Huckle, 1997).

Statistical analysis

It was not possible to replicate the experimental paddock systems adopted within these experiments due to constraints in the roadways necessary to access a network of small paddocks and difficulties incurred in providing water supply to a replicated paddock system. In addition, it would have been impossible to apply slurry within the smaller paddocks that would have been necessary within a replicated paddock system. For this reason individual cows were used as the experimental units. Four cows were removed from Experiment 2 due to health issues unrelated to the experimental treatments, and treated as missing values within the statistical analysis. These animals were replaced with animals of similar breed, parity and live weight to maintain equal cow numbers across treatments. Mean daily milk yields over both experimental periods, and weighted milk composition data for fat, protein and lactose were analyzed by ANOVA (Experiment 1) and REML variance components analysis (Experiment 2), using the corresponding pre-experimental data as covariates. Breed and parity were included as factors within these models. Mean daily milk yields and milk composition (fat and protein) within each of the seven individual grazing rotations in both experiments were analyzed using REML component analysis, with breed and parity included in the model. Live weight, body condition score and grazing behaviour data were analyzed by REML, including breed and parity within the model (Genstat 5, Release 3.2, Lawes Agricultural Trust, Rothamsted, UK).

RESULTS

Mean monthly rainfall during May, June, July, August and September was 13, 55, 125, 206 and 88 mm in Experiment 1, and 51, 232, 171, 118 and 23 mm in Experiment 2, respectively. The 10-yr average (1997-2006) monthly rainfall recorded at this site during May, June, July, August and September was 73, 67, 65, 74, and 78 mm, respectively. Average hours of sunshine during May, June, July, August and September were 7.4, 5.1, 4.3, 1.9 and 2.6 h d^{-1} in Experiment 1, and 7.6, 3.9, 4.6, 3.7 and 3.5 h d^{-1} in Experiment 2, respectively. The 10-yr average (1997-2006) during May, June, July, August and September for hours of sunshine at this site were 6.3, 5.1, 4.9, 5.0 and 4.0 h d^{-1}.

The mean chemical composition of the slurry applied during Experiments 1 and 2 is presented in Table 3. The mean DM content of the slurry applied within these experiments ranged from 63.0 to 78.1 g kg^{-1}, with the ammonia N content ranging from 1745 to 2485 mg kg^{-1} fresh.

Sward variables

The chemical composition of herbage offered (based on weekly samples), was numerically similar across treatments within Experiment 1 (Table 4). While a statistical comparison was not possible, herbage CP concentrations were numerically higher within the fertilizer only treatments in Experiment 2.

Average pre- and post-grazing sward heights with the fertilizer only and fertilizer plus slurry treatments in Experiment 1 were 10.1 and 10.5 (s.d. 1.65 and 1.86), and 5.7 and 5.9 (s.d. 1.01 and 1.01) cm, respectively (Table 5). Average pre-grazing sward heights within Experiment 2 were 10.3 (s.d. 2.40), 11.3 (s.d. 2.60) cm for the fertilizer only and fertilizer plus slurry treatment, respectively (high stocking rate) and 11.5 (s.d. 2.50), and 11.7 (s.d. 2.45) cm for these same two treatments at the normal stocking rate. The respective average post-grazing sward heights were 5.1 (s.d. 1.14), 5.4 (s.d. 1.25), 6.1 (s.d. 1.41), and 6.1 (s.d. 1.29) cm for these four treatments (Table 6).

Cow performance

In Experiment 1, none of average daily milk yield, total milk output, milk fat and protein composition, fat plus protein yield, milk energy content and milk energy output were affected by treatment ($P > 0.05$) (Table 7). Similarly there was no difference ($P > 0.05$) between treatments in average daily milk yield during any of grazing rotations 1-7 (Figure 1). Milk lactose was significantly lower ($P < 0.05$) with the fertilizer plus slurry treatment than with the fertilizer only treatment in Experiment 1 (44.2 vs. 44.9 g kg^{-1}). Treatment had no effect on either cow body condition score or live weight at the end of the study ($P > 0.05$). None of the grazing behaviour parameters recorded during the fifth grazing rotation in Experiment 1 were affected by treatment (Table 8).

With the exception of milk lactose content ($P < 0.05$), there were no significant interactions between stocking rate and N source for any other cow performance parameters examined in Experiment 2 (Table 9). Average daily milk yield and total milk output were reduced with the higher stocking rate treatment ($P < 0.01$) and with the fertilizer and slurry treatments ($P < 0.05$) (Table 9). Source of nitrogen applied in Experiment 2 had no effect on milk composition (fat, protein or lactose), milk fat plus protein yield, milk energy content and milk energy output ($P > 0.05$), while fat plus protein yield and milk energy output were reduced at the higher stocking rate ($P < 0.01$). There was no effect of treatment ($P > 0.05$) on average daily milk yield during each of grazing rotations 1-7 in Experiment 2 (Figure 2). Treatment had no significant effect on either cow body condition score or live weight at the end of the study ($P > 0.05$).

DISCUSSION

The primary objective of these experiments was to examine the performance of rotationally grazed dairy cows when a proportion of inorganic fertilizer N was replaced with a similar amount of available N (ammonia N) from slurry, the latter being applied using the trailing-shoe technique. As it was not possible to take a representative slurry sample and have it analyzed prior to slurry being applied, slurry application rates were calculated assuming the slurry to have a total N content of 3.5 g kg^{-1} and an available N proportion of 0.4 of total N (Frost *et al.*, 2007). While the ammonia N content of slurry in Experiment 1 was higher than assumed (proportionally 0.61 of total N), the total N content of the slurry was lower than assumed (2.9 g kg^{-1} fresh). Consequently, 80 kg of inorganic N was replaced by 88 kg of available N from slurry, a close match. However, while the mean N content of slurry applied within Experiment 2 was equal to the assumed value (3.5 g kg^{-1}), the ammonia N content of the slurry was higher than assumed (proportionally 0.63 of total N). As a consequence, the available N supplied from the four slurry applications (231 kg ha^{-1}) was higher than the 152 kg inorganic N replaced.

Replacing fertilizer N with slurry N might impact on cow performance via a number of mechanisms, including affecting the quantity, nutritive value and palatability of the herbage grown, or by having a detrimental effect on animal health. For example, previous studies have shown the grazing behaviour of dairy heifers (Pain *et al.*, 1974) and dairy cows (Pain and Broom, 1978) to be adversely affected when slurry was applied to swards using the splash plate application technique. Similarly, Danby *et al.* (1997a) observed an adverse effect on milk yield and liveweight gain when dairy cows grazed paddocks treated with slurry (applied by splash plate), with these effects persisting for at least five weeks after slurry application. These authors suggested that these responses were largely due to a herbage palatability effect, and in particular the detrimental impact of the smell of the applied slurry. A similar behaviour response is observed when cattle graze around dung pats (Marten and Donker, 1966). However, the impact on dairy cow performance of applying slurry using a trailing-shoe system does not appear to have been examined previously.

The results of Experiment 1 clearly demonstrate that, with the exception of milk lactose content, replacing 80 kg fertilizer N with a similar quantity of available N from slurry had no effect on cow performance. This is perhaps not surprising when sward height, herbage composition and grazing behaviour data from this experiment are examined. Although a statistical analysis of the sward height and herbage composition data was not possible, mean pre- and post-grazing sward height data suggest that the quantity of herbage available was similar with both treatments. This was also the case during the two rotations following slurry application (second and fifth grazing rotations), when post-grazing sward heights averaged 6.0 cm and 5.8 cm for the fertilizer only and fertilizer plus slurry treatments, respectively. Similarly, mean utilization rates of available herbage (>4 cm) during the entire experiment were proportionally 0.73 and 0.71 for the fertilizer only and fertilizer plus slurry treatments, respectively, and 0.68 and 0.71 for the fertilizer only and fertilizer plus slurry treatments during the two grazing rotations immediately after slurry application. In addition, herbage composition data suggests that treatment had little effect on either herbage CP or ME content. While grazing behaviour was only measured during the fifth grazing cycle, a cycle immediately following slurry application, none of the grazing behaviours examined were affected by treatment. This contrasts to the earlier findings of Pain and Broom (1978), who found that dairy cows grazed less efficiently (grazed for longer but removed less grass), spent less time lying, and ruminated less frequently when grazing swards following the application of slurry using the splash plate technique. Nevertheless, in a second study these authors observed no detrimental effect on herbage intake or grazing behaviour of dairy cows when cattle slurry was applied to grazing paddocks by injection on two occasions during the summer. Thus the findings of the latter study lend support to the findings of the current study, namely that when slurry is applied using a technique which minimizes contact with herbage, the detrimental effects of slurry application on dairy cow performance can be largely avoided. While there would appear to be no obvious explanation for the effect of treatment on milk lactose content, the difference recorded is of little biological importance. Thus the results of Experiment 1 clearly demonstrated that approximately 29% of fertilizer N could be replaced by slurry N without any adverse effects on cow performance, when applied using the trailing-shoe technique.

Experiment 2 was designed to examine the use of slurry on grazing swards under more challenging conditions, namely when slurry was applied more frequently, and when cows were forced to graze tighter through the use of higher stocking rates. The reduction in milk and fat plus protein output with the high stocking rate treatments is not unexpected, with previous research having shown that within a grazing situation herbage allowance is a major driver of dairy cow performance (Peyraud *et al.,* 1996). Within the current experiment mean herbage allowances (>1,600 kg DM ha^{-1}) across the grazing season were 15.0 and 20.0 kg DM cow^{-1} d^{-1} for the high and normal stocking rate treatments respectively (derived from pre-grazing sward heights, as described by Dale *et al.,* 2006), with each 1.0 kg DM cow^{-1} d^{-1} reduction in herbage allowance resulting in a 0.3 kg reduction in daily milk yield. This compares with 0.27 kg reduction in milk yield per kg reduction in herbage allowance (24.0 to 15.9 kg DM cow^{-1} d^{-1} (>3.5 cm)) presented by Maher *et al.* (2003). However, while previous studies have observed a decrease in milk protein content with decreasing herbage allowance (Curran *et al.*, 2010), herbage allowance had no effect on milk composition in the current study. The increase in stocking rate, and associated reduction in herbage allowance in Experiment 2 achieved its objective, namely forcing the cows to graze tighter. This was reflected in mean post-grazing sward heights of 5.3 and 6.1 cm for the high and normal stocking rate treatments, respectively.

In contrast to the findings of Experiment 1, source of N had a significant effect on milk output in Experiment 2, with cows that grazed swards that had slurry applied on four occasions during the season having a lower milk yield than cows grazing the fertilizer only treatment swards. However, in common with the findings of Experiment 1, N source in Experiment 2 had no effect on either milk fat or milk protein content, or on fat plus protein yield, while in contrast to Experiment 1, milk lactose was unaffected by treatment.

While no significant N source x stocking rate interaction was identified for milk output, a comparison of individual treatment means highlights that the N source effect on milk output was largely a consequence of the lower milk yield observed within the fertilizer plus slurry treatment at the high stocking rate, with the mean daily milk yield with this treatment being 1.5 kg cow^{-1} d^{-1} lower than with the fertilizer only treatment. A number of factors may have contributed to this reduction in milk yield. For example, WSC, ME and CP concentrations of the herbage with the fertilizer plus slurry treatment were numerically lower than for the fertilizer only treatment. Nevertheless, these differences were small, and the values were in fact similar to those observed within the fertilizer plus slurry treatment at the normal stocking rate.

However, mean post-grazing sward height data suggest that cows on the fertilizer plus slurry treatment (high stocking rate) may not have grazed as tightly as those on the fertilizer only treatment, although these trends were largely confined to the first two grazing rotations. Nevertheless, it is possible that when cows were forced to graze tighter under a high stocking rate scenario, cows may have been forced to graze closer to the base of the sward where the sward may have been contaminated with slurry or where slurry odours may have been present. This may have had a negative effect on grazing behaviour, with cows more likely to reject herbage from swards treated with slurry when grazing these swards more tightly. This in turn may have resulted in lower intakes, and might help explain the lower milk production observed. Data presented in Figure 2 clearly highlights that this effect became obvious shortly after treatments were implemented, namely during the second grazing cycle. Nevertheless, part of the difference in post-grazing sward height can be attributed to the greater pre-grazing sward height that was observed with the fertilizer plus slurry treatment (which occurred irrespective of stocking rate). It is possible that following the first slurry application, a rapid uptake of available slurry N by the sward could have resulted in the higher pre-grazing sward heights observed within these treatments. Nevertheless, the CP analysis of herbage during this period was similar between treatments.

While rejection of contaminated herbage may have been an issue with the high stocking rate slurry treatment, cows on the high stocking rate treatments achieved mean herbage utilization efficiencies (>4.0 cm) of proportionally 0.83 and 0.81 (fertilizer only and fertilizer plus slurry treatments, respectively), in comparison to a utilization efficiency of 0.73 with the normal stocking rate treatments. These levels of herbage utilization (with the high stocking rate treatment) are considerably higher than those previously achieved with surface applied slurry (Pain and Broom, 1978), and are indicative of high grazing efficiencies. Indeed herbage utilization rates within these experiments tended to be at the upper end of the range of those recorded on dairy farms in England, namely proportionally 0.44-0.83 (Peel and Matkin, 1984; Peel *et al.*, 1986).

While the results of Experiments 1 and 2 suggest that provided cows are not grazing overly tightly, fertilizer N can be replaced with similar quantities of available N from slurry without adverse effects on dairy cow performance, the impact of the weather does need to be considered. For example, it is known that weather conditions (rainfall intensity, temperature) can have a major influence on the efficiency of utilization of nutrients applied as both inorganic fertilizers (Jarvis *et al.,* 1991) and as animal manures (McGinn and Sommer, 2007; Mkhabela *et al.*, 2009). For example, the above average rainfall during June, July and August in each of Experiments 1 and 2 may have helped wash slurry from the grass leaf down into the lower sward canopy, thus improving herbage palatability. A similar effect was observed by Laws *et al.* (1996) who, when working with grass turves (0.25 m^2) treated with slurry, observed an improvement in the grazing behaviour of beef steers when rainfall was simulated (equivalent to 12.2 mm) immediately after slurry was applied. However within the current study it was also observed that when slurry was applied during dry weather, the bands of slurry at the base of the sward dried out quite quickly, and it is expected that this may have reduced odours associated with the slurry. It is of course true that N volatilization losses are likely to have increased during hot dry weather, thus reducing N available for sward re-growth.

As highlighted earlier, applying slurry to grass swards could expose cows to potentially dangerous pathogens. This risk has been highlighted previously when the splash plate technique has been used, and the whole sward canopy covered in slurry (Rankin and Taylor, 1969). However in studies involving the splash plate grazing normally took place 3-4 weeks after slurry was applied (Laws and Pain, 2002; Danby *et al.*, 1997b). However, the trailing-shoe technique does allow grazing to take place within 10–20 days of slurry being applied (as in the current study), and as such the risk of exposure to pathogens might be increased. Nevertheless, this risk is likely to be substantially reduced when the trailing-shoe technique is used, as the contamination of the grass leaf with slurry during application is much reduced compared to splash plate. Indeed, this has been demonstrated through improved silage fermentation characteristics following slurry application via a trailing-shoe (compared to a splash plate) to grass prior to silage harvesting (Laws *et al.*, 2002). Nevertheless, the risk of exposure of grazing livestock to pathogens following slurry applications using low trajectory techniques does not appear to have been examined, and is an issue that needs to be considered.

While these experiments highlight that slurry can be applied to grazing swards using low trajectory techniques without having detrimental effects on animals performance/grazing behaviours as observed previously with the splash plate technique (Pain and Broom, 1978; Danby *et al.*, 1997a; Laws and Pain, 2002), the impact on field nutrient balance of using slurry within grazing systems must be considered. For example, unlike in a cutting scenario, ‘recycling’ of N, P and K occurs within a grazing system, when faeces and urine are deposited by the grazing animal. Indeed at the slurry applications adopted in Experiment 2, nutrient surpluses, and especially P surpluses, are likely to occur, and as such caution is required, especially at higher application rates.

CONCLUSIONS

Inorganic fertilizer inputs were reduced by 80 and 152 kg N ha^{-1} within the fertilizer and slurry treatments in Experiments 1 and 2, respectively, without having a detrimental effect on cow performance at a 'normal' stocking rate. However when cows were forced to graze tighter, milk yield was reduced within the treatment involving slurry applications.

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Table 1 Summary of rotation length and stocking rates within each of Experiments 1 and 2

	Experiment 1			**Experiment 2**			
						Stocking rate (cows/ha)	
Experimental rotation number	**Rotation length (d)**	**Days when cows housed**	**Stocking rate (cows/ha)[b]**	**Rotation length (d)**	**Days when cows housed**	**High[c]**	**Normal[d]**
1[a]	20	0	6.0	14	0	10.4	8.6
2	24	0	5.0	25	0	5.6	4.7
3	24	0	5.0	21	0	6.9	5.8
4	22	0	5.5	26	6	7.3	6.1
5	26	5	5.7	28	3	5.6	4.7
6	26	4	5.5	26	0	5.6	4.7
7[a]	8	0	-	21	0	6.9	5.8

[a] First and last day of Experiment was 28 April and 24 September in Experiment 1, and 30 April and 7 October in Experiment 2
[b] Paddock size 0.20 ha; [c] Paddock size, 0.103 ha; [d] Paddock size, 0.124 ha

Table 2 Actual application rates of inorganic fertilizer nitrogen and cattle slurry within Experiments 1 and 2

	Experiment 1					Experiment 2				
	Fertilizer only	Fertilizer and slurry				Fertilizer only	Fertilizer and Slurry			
			Slurry					Slurry		
	Fertilizer N (kg ha^{-1})	Fertilizer N (kg ha^{-1})	t ha^{-1}	kg N ha^{-1}	kg available N ha^{-1}	Fertilizer N (kg ha^{-1})	Fertilizer N (kg ha^{-1})	t ha^{-1}	kg N ha^{-1}	kg available N ha^{-1}
Pre-turnout application	28	28	-	-	-	28	28	-	-	-
During non-experimental rotation	60	60	-	-	-	60	-	39.9	135	83
During 1st rotation	50	-	31.0	93	56	50	50	-	-	-
During 2nd rotation	40	40	-	-	-	40	-	27.4	98	68
During 3rd rotation	30	30	-	-	-	30	30	-	-	-
During 4th rotation	30	-	18.6	52	32	25	25	-	-	-
During 5th rotation	22	22	-	-	-	30	-	18.1†	61	32
During 6th rotation	20	20	-	-	-	22	-	19.2†	70	48
During 7th rotation	0	0	-	-	-	0	0	-	-	-
Total N	**280**	**200**			**88**	**285**	**133**			**231**

†Difficult ground conditions prevented slurry from being applied to 8 and 3 paddocks during the fifth and sixth grazing rotations, respectively: inorganic fertilizer N was applied instead

Table 3 Mean chemical composition of the slurry applied within Experiments 1 and 2

Grazing rotation		Chemical composition			
		Oven dry matter (g kg^{-1})	Total N (g kg^{-1} fresh)	Ammonia N (mg kg^{-1} fresh)	pH
Experiment 1	First	67.5	3.0	1792	7.5
	Fourth	72.7	2.8	1745	7.6
Experiment 2	Pre-experimental	63.0	3.4	2089	7.4
	Second	67.4	3.6	2474	7.7
	Fifth	75.3	3.3	1783	7.8
	Sixth	78.1	3.6	2485	8.1

Table 4 Average chemical composition of herbage sampled within each treatment during Experiments 1 and 2 (g kg^{-1} DM, unless stated otherwise)

	Experiment 1		Experiment 2			
			High Stocking rate		Normal stocking rate	
	Fertilizer only	Fertilizer and slurry	Fertilizer only	Fertilizer and slurry	Fertilizer only	Fertilizer and slurry
Water soluble carbohydrate	126	128	158	143	147	146
Acid detergent fibre	267	261	271	276	270	278
Crude protein	197	202	192	181	195	184
Metabolisable energy (MJ kg DM^{-1})	11.7	11.8	11.6	11.4	11.5	11.4

Table 5 Average pre- and post-grazing sward heights (cm) measured within each grazing rotation during Experiment 1

Experimental grazing rotation	**Fertilizer only**		**Fertilizer and slurry**	
	Pre-grazing	**Post-grazing**	**Pre-grazing**	**Post-grazing**
1	10.4	5.8	11.2	6.4
2#	9.8	5.8	9.8	5.6
3	9.1	5.2	9.2	5.2
4	10.7	6.5	11.5	6.6
5#	10.7	6.2	11.0	6.2
6	10.2	5.5	11.1	5.8
7	9.4	4.8	9.9	5.5
Overall mean (150 d)	10.1	5.7	10.5	5.9

Grazing rotation immediately following slurry application

Table 6 Average pre- and post-grazing sward heights (cm) measured within each grazing rotation during Experiment 2

Experimental grazing rotation	**High stocking rate**				**Normal stocking rate**			
	Fertilizer only		**Fertilizer and slurry**		**Fertilizer only**		**Fertilizer and slurry**	
	Pre-grazing	**Post-grazing**	**Pre-grazing**	**Post-grazing**	**Pre-grazing**	**Post-grazing**	**Pre-grazing**	**Post-grazing**
1#	12.2	5.4	14.7	6.4	12.2	6.9	13.5	6.6
2	11.3	5.1	11.7	5.8	12.0	6.0	12.0	6.5
3#	10.8	5.2	11.4	5.3	12.4	6.3	11.8	6.1
4	10.2	5.0	11.1	5.2	12.1	5.8	12.0	6.0
5	9.4	4.9	10.8	5.4	10.8	5.9	11.1	6.0
6#	9.7	5.1	10.9	5.1	10.9	5.9	11.4	5.8
7#	8.9	4.8	10.0	4.9	10.3	5.5	10.7	5.7
Overall mean (161 d)	10.3	5.1	11.3	5.4	11.5	6.1	11.7	6.1

Grazing rotation immediately following slurry application

Table 7 Effect of source of applied nitrogen (fertilizer only vs fertilizer and slurry) on dairy cow performance in Experiment 1

	Treatment			
	Fertilizer only	**Fertilizer and slurry**	**s.e.m**	**Significance**
Daily milk yield (kg)	19.2	18.8	0.41	NS
Total milk output ($kg\ cow^{-1}$: 150 days)	2882	2820	62.0	NS
Milk composition ($g\ kg^{-1}$)				
Fat	42.2	42.1	0.68	NS
Protein	35.3	35.2	0.37	NS
Lactose	44.9	44.2	0.19	*
Fat + protein yield ($kg\ d^{-1}$)	1.48	1.43	0.025	NS
Milk energy content ($MJ\ kg^{-1}$)	3.19	3.18	0.034	NS
Milk energy output ($MJ\ cow^{-1}\ d^{-1}$)	60.9	59.1	1.04	NS
Body condition score at end of experiment	2.3	2.3	0.09	NS
Live weight at end of experiment (kg)	531	532	11.6	NS

NS, not significant; *, $P < 0.05$

Table 8 Effect of source of applied nitrogen on the grazing behaviour of animals during a four-day period within the fifth grazing rotation in Experiment 1

	Treatment			
	Fertilizer only	**Fertilizer and slurry**	**s.e.d.**	**Significance**
Total number of bites (bites d^{-1})	22669	22026	1526	NS
Biting rate (bites min^{-1})	51	52	1.9	NS
Grazing time (mins d^{-1})	448	430	30.5	NS
Ruminating time (mins d^{-1})	267	252	33.2	NS
Grazing:ruminating	1.7	1.8	0.20	NS
Boli produced (number d^{-1})	336	306	42.3	NS

Table 9 Effect of stocking rate (high vs normal) and source of applied nitrogen (fertilizer only vs fertilizer and slurry) on dairy cow performance in Experiment 2

	Treatments				Significance			
	High stocking rate		Normal stocking rate					
	Fertilizer only	Fertilizer and slurry	Fertilizer only	Fertilizer and Slurry	s.e.d.	Nitrogen source	Stocking rate	Stocking rate x nitrogen source
Daily milk yield (kg)	19.1	17.6	20.2	19.6	0.63	*	**	NS
Total milk output (kg cow^{-1} : 161 days)	3051	2815	3225	3141	100.6	*	**	NS
Milk composition (g kg^{-1})								
Fat	42.7	43.7	42.2	41.8	1.18	NS	NS	NS
Protein	34.0	34.6	34.9	34.6	0.58	NS	NS	NS
Lactose	44.8	43.7	44.2	44.3	0.34	NS	NS	*
Fat + protein yield (kg d^{-1})	1.44	1.39	1.56	1.50	0.046	NS	**	NS
Milk energy content (MJ kg^{-1})	3.17	3.22	3.17	3.15	0.053	NS	NS	NS
Milk energy output (MJ cow^{-1} d^{-1})	59.9	56.9	64.0	61.9	1.85	NS	**	NS
Body condition score at end of experiment	2.6	2.4	2.7	2.6	0.10	NS	NS	NS
Live weight at end of experiment (kg)	542	528	547	546	16.4	NS	NS	NS

NS, not significant; *, $P < 0.05$; **, $P < 0.01$

Figure 1 Effect of fertilizer only (shaded bars) or fertilizer and slurry applications (unshaded bars) on average daily milk yield during each grazing rotation within Experiment 1 (slurry was applied during the first and fourth grazing rotation)

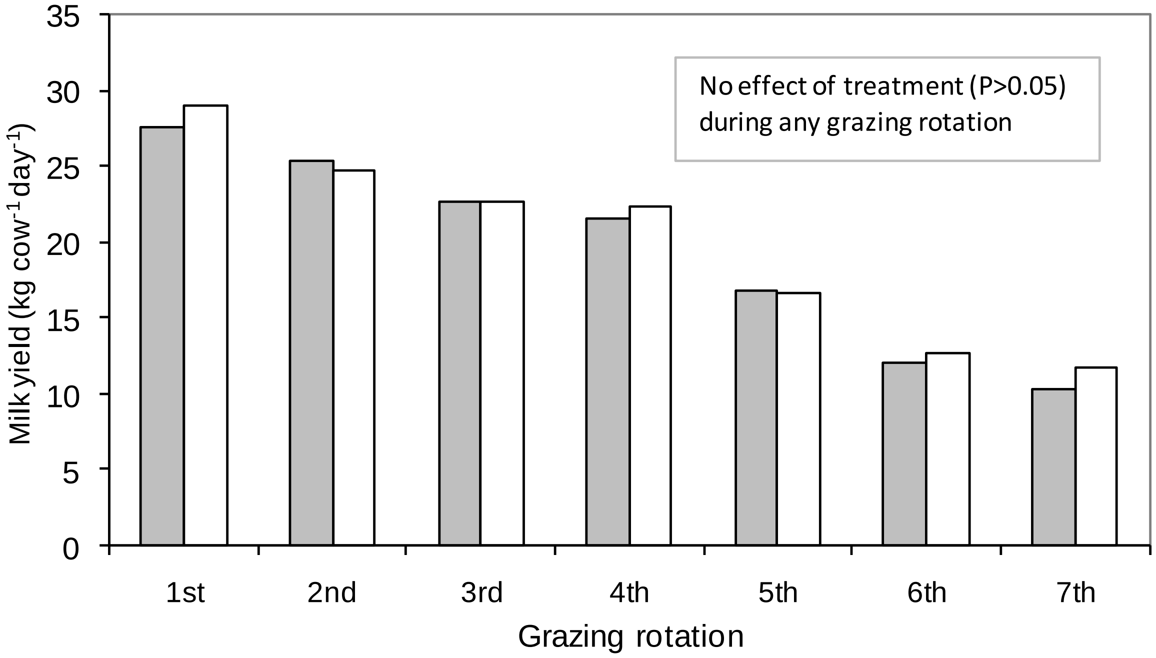
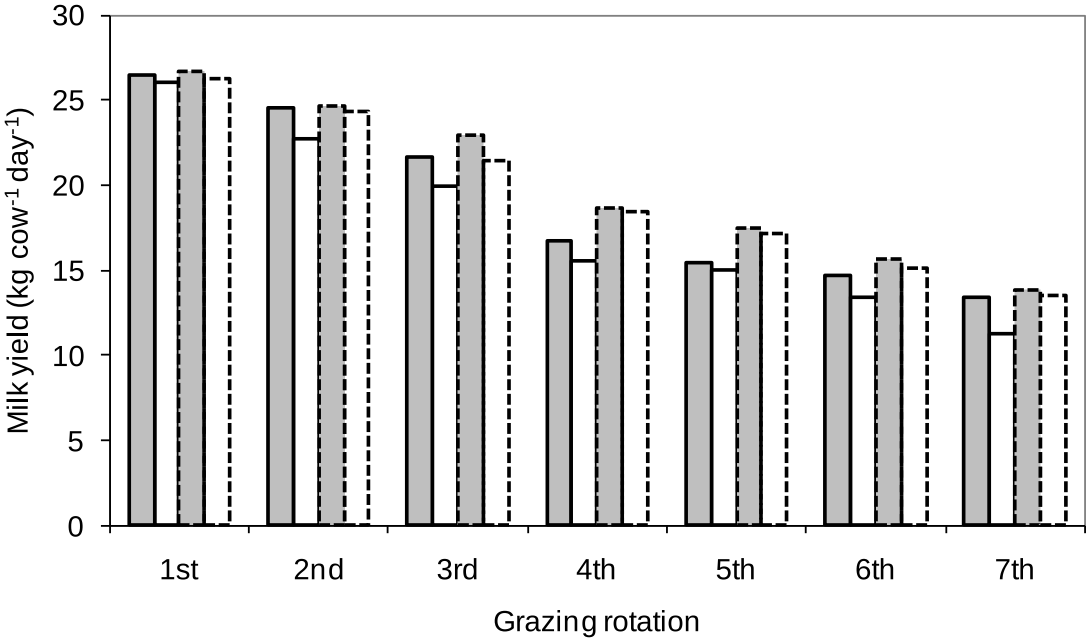


Figure 2 Effect of grazing stocking rate ('High' solid bar border; 'Normal' dashed bar border) and fertilizer only (shaded bars) or fertilizer and slurry applications (unshaded bars) on average daily milk yield during each grazing rotation within Experiment 2 (slurry was applied prior to the first grazing rotation, and then during the second, fifth and sixth rotation)



KEY PRESENTATIONS

Scientific publications

- Dale, A.J., Ferris, C.P., Frost, J.P., Mayne C.S. and Kilpatrick, D.J. (2011) The effect of applying cattle slurry within rotational grazing systems using trailing-shoe technology on dairy cow and sward performance. *Grass and Forage Science*, submitted

Presentations at conferences

- Dale, A.J., Mayne, C.S. and Frost, J.P. (2009) Evaluation of the potential of a trailing shoe system to incorporate cattle slurry into a dairy rotational grazing system. *Proceedings of the Agricultural Research Forum*, Tullamore, March 2009. Page 32
- Dale, A.J., Mayne, C.S. and Frost, J.P. (2009) Effect of slurry application via trailing shoe system on dairy cows performance within rotational grazing system. *Proceedings of the Agricultural Research Forum*, Tullamore, March 2009. Page 41

Other publications

- Using slurry on grazing land – opportunities to save on fertilizer costs. United News, November 2007
- Making better use of slurry during the grazing season. AgriSearch dairy sector update, Autumn 2008
- The effect of applying slurry during the grazing season on dairy cow performance. AgriSearch farmers booklet, February 2011

Presentations to farmer/industry groups visiting Hillsborough

• Paul McGill	6th Aug 2010
• 16 farmers involved in ‘Dairyman’ project	26th July 2010
• 35 Greenmount HND year 1 students	23rd April 2010
• 16 dairy farmers from Navan	3rd Feb 2010
• Nitrates Directive stakeholders	24th Nov 2009
• 15 Dairy farmers from Welsh Borders and Shropshire	30th Sept 2009
• Senior DEFRA officials (climate change) and AFBI staff	30th July 2009
• Blacklion dairy discussion group	6th May 2009
• Australian student	9th Dec 2008
• Dr Mike Williams, North Carolina State University	31st Oct 2008
• Gary Nolan and Navan grazing group	3rd Oct 2008

- Heads of Departments, Farmer Representatives, and Chamber of Agriculture, Lower Saxony, Germany — 12th Sept 2008
- Hugh Black and 6 GB dairy farmers — 10th Sept 2008
- Alan Warnock + Fermanagh Grassland Club members — 26th Aug 2008
- Ian Carrick and 40 Market Hill dairy farmers — 2nd July 2008
- Dr Pat Dillon, TEAGASC, Moorepark — 1st July 2008
- Prof. John Comerford, Pennstate University — 4th Apr 2008
- Adrian Caine + 9 dairy farmers — 11th Dec 2007
- BOCM Pauls Ltd technical staff + 8 farmers — 26th Oct 2007
- 15 Chilean dairy farmers — 12th Oct 2007
- 12 Devon dairy farmers + Alltech — 24th July 2007
- Dairy Hygiene Inspectorate (approx 30) — 17th July 2007
- Hybrid dairy discussion group (Devon and Cornwall) — 27th Jun 2007
- Frank Wright Group – 24 Ruminant Nutritionists and technical staff — 26th Jun 2007