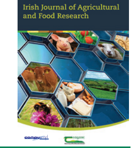

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# Effects of early spring N-fertilisation strategies on grass production and nitrogen recovery

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**Abstract**

***Application rate and application date of fertiliser nitrogen (N) are important factors determining grass production response and N recovery by grassland in spring. This study was conducted at two sites with different soil types (sandy loam and clay loam) in Ireland in spring 2005 and 2006. In comparison with a non-fertilised (zero-N) control, urea N was applied at rates of 60 and 90 kg N/ha either as single or split applications on eight dates ranging between 11 January and 14 March. Grass was harvested on four occasions between 21 February and 25 April. Split fertiliser N applications provided the best outcome in relation to grass DM production, apparent recovery of fertiliser N (ARFN) and cost of additional grass produced compared with single applications. Likewise, in this study the optimum date to commence fertiliser N application was 21 January combined with a second application on 26 February in terms of the cost-effectiveness of the fertiliser N input to increase grass DM production.***

**Keywords**

*Apparent recovery of fertiliser nitrogen • application date • application rate • grass production • nitrogen uptake*

## Introduction

Grazed grass constitutes 60–75% of the diet of dairy cows in Ireland and is widely recognised as the cheapest form of feed for milk production (Dillon *et al.*, 1995). Accumulated evidence has shown that in a typical Irish system of dairy production, a compact calving pattern in springtime in conjunction with an early turnout date to pasture has clear economic advantages (Dillon & Crosse, 1994; Sayers & Mayne, 2001; Dillon *et al.*, 2002; Kennedy *et al.*, 2005; Kennedy *et al.*, 2007; McEvoy *et al.*, 2010). However, in Ireland there is little net growth of grass during the winter period due to low temperatures and low incidental solar radiation (Hennessy *et al.*, 2008). As a result, management strategies are necessary to increase grass availability in the late winter and early spring. The application of fertiliser N in spring has an important role in achieving this objective (Laidlaw *et al.*, 2000; O'Donovan *et al.*, 2004).

During the recent decades, there have been a number of studies examining the impacts of application date and application rate of fertiliser N on grass production for grazing in early spring (Van Burg, 1968; Murphy, 1977; Stevens *et al.*, 1989; Long *et al.*, 1991; Laidlaw *et al.*, 2000; O'Donovan *et al.*, 2004; Murphy *et al.*, 2013). However, these experiments usually only entailed comparing single applications of fertiliser N applied at a range of application rates and on a range of application dates, which were typically between early January and mid-March. Grass production response was quantified in terms of grass harvested on one or two dates, typically in mid-March and/or mid-April. While the results suggest a clear grass production response to fertiliser nitrogen (N) application, the optimum date for application of fertiliser N was less clearly identifiable. On Irish dairy farms, fertiliser N is typically applied to grassland using a number of applications throughout the growing season with the purpose of increasing grass availability for grazing livestock (Humphreys *et al.*, 2003; Dillon *et al.*, 2009). In certain instances, this can be on up to 10 occasions per year (Treacy, 2008; Treacy *et al.*, 2008). However, fertiliser N has become much more expensive relative to farm gate product prices in recent years (Humphreys *et al.*, 2012), and there is increasing pressure in many western European countries to improve the apparent recovery of fertiliser nitrogen (ARFN) in order to lower any potential negative impact on the environment (Van Grinsven *et al.*, 2013).

While single large applications in spring have been shown to give the best grass production responses, they are also

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associated with lower ARFN and in most instances the residual impact on subsequent grass production later in the spring was not taken into account. Therefore, the objective of this study was to investigate whether combinations of two (split) applications of fertiliser N would result in higher grass production and ARFN in comparison with single applications of fertiliser N in spring. Specific objectives were to (a) determine the effect of single or split N application on grass production and ARFN and (b) identify the most appropriate dates for fertiliser N application during springtime.

## Materials and methods

### *Experimental site characteristics*

The experiment was conducted at the Teagasc Animal and Grassland Research and Innovation Centre at Moorepark (52° 09′ N, 08° 15′ W; altitude 50 m above sea level [ASL]) and at the Teagasc Solohead Research Farm (52° 51′ N; 08° 21′ W; altitude 150 m ASL).

The topography of the Moorepark site is gently rolling. The soil is classified as a free-draining acid brown earth (Cambisol) of sandy loam to loam texture. Soil pH, total N and total C content in the surface 10 cm of soil were 6.5%, 0.48% and 4.48%, respectively. The site drains quickly following periods of high rainfall.

The topography of the Solohead site is relatively flat. The soil is classified as a poorly drained gley (Gleysol; 90%) and a grey-brown podzolic (10%) with a clay loam texture. Soil pH, total N and total C content in the surface 10 cm of soil were 6.5%, 0.54% and 5.35%, respectively. The site tends to remain waterlogged after periods of high rainfall.

The local climate at both sites is maritime in nature and there is a long potential growing season of between 270 and 300 d (Brereton, 1995).

### *Experimental layout and design*

This study was conducted at both sites in 2005 and 2006. Prior to this study, the grassland had been renovated at both sites in 1999 and sown with perennial ryegrass (*Lolium perenne* L. cv. Magella). Both sites were used for pasture-based dairy production following renovation prior to the commencement of the study in 2005. A soil test at the beginning of the study indicated no requirement for the application of lime. Phosphorous (P) and potassium (K) concentrations determined using the Morgan's test (Na acetate + acetic acid, pH 4.8) were sufficient to meet grass growth requirements at both sites (15.3 and 31.2 mg/L P and 185 and 196 mg/L K at Moorepark and Solohead, respectively).

Grassland plots (3 m × 5 m) were laid out in a randomised complete block design. Three blocks were laid down at each site in 2005 and the number of blocks was increased to four at each site in 2006. Within each block, there were 32 main plots. There were eight application rates of fertiliser N including a non-fertilised control (0 + 0; Table 1). The eight application rates were applied as a single or a combination of two (split) applications of a total of 60 or 90 kg N/ha of fertiliser N (Table 1).

Each of these eight fertiliser N application rate treatments were applied on eight dates (Table 1) during the spring. Where applications were split, there was approximately 5 wk between the first and second application (Table 1). Fertiliser N was applied by hand in the form of fine crystalline solid of urea (46% N).

Each of the 32 main plots were divided into four sub-plots measuring 0.75 m × 5 m each. Each sub-plot was randomly assigned to each of four harvest dates: 21 February (H1), 14 March (H2), 4 April (H3) and 25 April (H4). Therefore, grass was harvested from one sub-plot on each harvest date, and the same area of each sub-plot was only harvested once during the experimental period in each year; thus, there was no harvesting of any subsequent regrowth. Grass harvesting was performed using a Honda rotary blade lawnmower (HRH 535; Honda, Swepsonville, NC, USA) with a cutting blade width of 0.55 m and cutting height of 4 cm. A 0.55-m-wide and

**Table 1:** Application rates (R) and dates (D) of fertiliser N and harvest dates (H) in this study

| Application rate (kg/ha of fertiliser N) | | | |
|---|---|---|---|
| | Rate on first application date | | Rate on second application date |
| 0 + 0 | 0 | | 0 |
| 0 + 60 | 0 | | 60 |
| 0 + 90 | 0 | | 90 |
| 30 + 30 | 30 | | 30 |
| 30 + 60 | 30 | | 60 |
| 60 + 0 | 60 | | 0 |
| 60 + 30 | 60 | | 30 |
| 90 + 0 | 90 | | 0 |
| **Application date of fertiliser N** | | | |
| D1 | 11 Jan | D5 | 21 Feb |
| D2 | 2 Jan | D6 | 26 Feb |
| D3 | 01 Feb | D7 | 07 Mar |
| D4 | 11 Feb | D8 | 14 Mar |
| **Grass harvest dates** | | | |
| H1 | 21 Feb | | |
| H2 | 14 Mar | | |
| H3 | 4 Apr | | |
| H4 | 25 Apr | | |

5-m-long strip was harvested along the centre of each sub-plot. This allowed a border of approximately 0.20 m between each sub-plot.

### *Grass sampling and analysis*

Harvested grass from each sub-plot was collected and weighed. A sub-sample of 100 g was dried for 16 h at 98°C in a forced air oven to a constant weight to determine dry matter (DM) content. A second 100 g sub-sample was dried at 40°C in forced draught oven for 48 h, and milled to pass a 2-mm screen. The concentration of N in the grass was determined by a LECO 528 auto analyser (LECO Corporation, St. Joseph, MI, USA).

### *Uptake of N in grass and ARFN*

Uptake of N in grass was calculated by multiplying grass DM yield by the N concentration in harvested grass. It was assumed that biological N fixation was negligible because there was no clover in the swards and N deposition in the region is low at approximately 6 kg/ha per year (Jordan *et al.*, 1997; Necpálová *et al.*, 2013). Apparent recovery of fertiliser N (N recovery efficiency) was calculated as the difference in N uptake between fertilised and unfertilised (zero-N) plots in each replicated block between application of fertiliser N and harvest of the grass and expressing this as a proportion of the total fertiliser N applied:

$$\mathrm{ARFN} = (N_U - N_0) / N_F$$

where

$N_U$ = N uptake in fertilised plots

$N_0$ = N uptake in zero-N plots

$N_F$ = applied fertiliser N

The ARFN was determined for H1–H4 for both years. The ARFN at H1 was determined for single applications of 30, 60 and 90 kg N/ha applied on application dates 11 January (D1), 21 January (D2), 1 February (D3) and 11 February (D4), and not for later single (21 February [D5], 26 February [D6], 7 March [D7], 14 March [D8]) or combined applications because the fertiliser N for the later treatments (D5–D8) had not been applied at that stage. As D8 coincided with H2, the ARFN at H2 was not determined for the (D4 + D8) date combination.

### *Calculating the cost of additional grass DM*

The cost of fertiliser N in the form of urea (46% N and €0.85/kg of N) was based on the average cost between 2008 and 2017 according to the central statistics office (CSO, 2018). Thus, the cost of N applied at 60 and 90 kg/ha was €51 and €77, respectively. Each additional kilogram of grass grown was estimated to contain 3 g/kg DM of P and 25 g/kg DM of K. The cost of fertiliser P was €2.55/kg and that of fertiliser K was €0.78/kg, based on the average cost of each between 2008 and 2017 (CSO, 2018). On this basis, the cost of fertiliser N applied and the imputed costs of P and K in the additional grass grown (as a consequence of the application of fertiliser N) were summed for the final harvest (25 April) for each plot in each year. A standard cost of €60/t of grass DM was included to account for ancillary costs. These were the opportunity cost of land at €50/t of grass DM, grassland renovation (every 20 yr) at €7.50/t of grass DM and the application of lime (every 5 yr) at €2.50/t of grass DM (Finneran *et al.*, 2012; O'Donovan *et al.*, 2011). The cost of fertiliser application, in terms of working time and machinery costs, was fixed on the basis of a contractor charge of €37/t of fertiliser applied (FCI, 2019).

### *Statistical analysis*

Grass DM production and N uptake in grass DM for each harvest date in each year were subjected to analysis of variance (ANOVA) using MSTAT (Freed *et al.*, 1989) and analysed as a two factor (application date × application rate) for examining the main effects of each factor and interactions between factors. At H1 in each year for grass DM production and N uptake in grass DM, only single applications of four levels of N (0, 30, 60 and 90 kg/ha) applied on D1, D2, D3 and D4 were included in the ANOVA. At H2 in each year for grass DM production and N uptake in grass DM, eight application rate treatments and three application date combinations were included in the ANOVA; the D4 + D8 date combination was not included. At H3 and H4 in each year for grass DM production and N uptake in grass DM, eight application rate treatments and four application date combinations were included in the ANOVA. Likewise, at H1, H2, H3 and H4 in each year ARFN was subjected to ANOVA for examining the main effects of each factor and interactions between factors. ARFN was not determined for the 0 treatment at H1 or the 0 + 0 treatment at H2, H3 or H4, as no fertiliser N was applied at these application rate treatments in either year. The cost of additional grass for H4 in each year was subjected to ANOVA for examining the main effects of each factor and interactions between factors.

## Results

### *Meteorological data*

Monthly rainfall and daily soil temperature at 10 cm depth during the experimental period and the 20-yr average for both are presented in Figure 1. With the exception of March, monthly rainfall in 2005 was higher than in 2006 at both sites. Total rainfall during the period encompassing 1 January to 30 April was 316 mm at Moorepark and 318 mm at Solohead in 2005. This rainfall amount was similar to the long-term average for both Moorepark and Solohead, being 326 and 330 mm, respectively. During the same period in 2006, there was much less rainfall at both sites with 247 mm at Moorepark

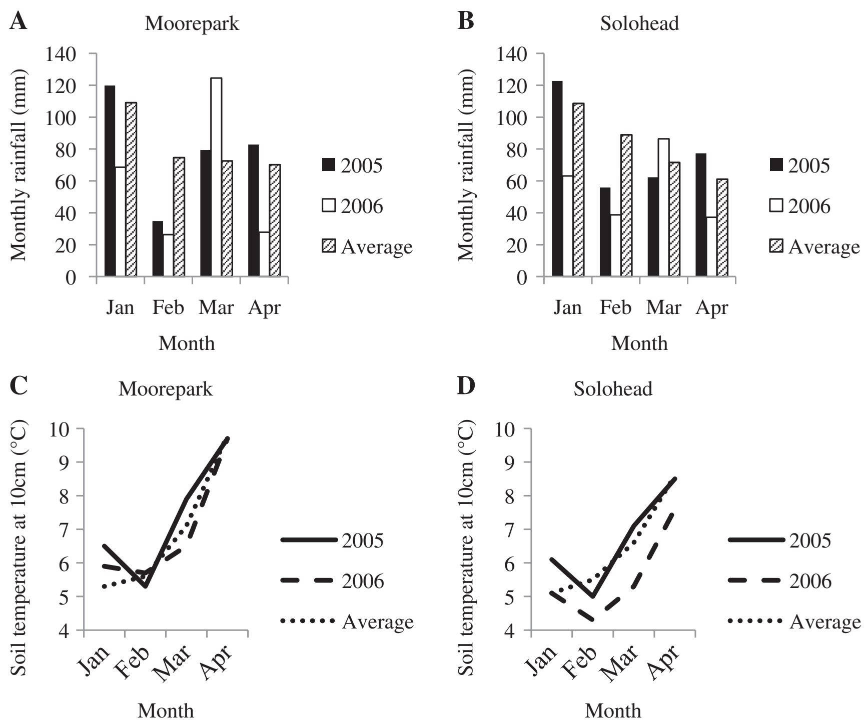


**Figure 1.** Monthly rainfall at (A) Moorepark and (B) Solohead and average monthly soil temperatures at 10 cm depth at (C) Moorepark and (D) Solohead in 2005, 2006 and 20-yr average.

(25% below average) and 225 mm at Solohead (32% below average).

In both years, daily soil temperature was lowest in February and highest in April. Average soil temperature during the experimental period was higher in 2005 (7.0°C) than in 2006 (6.3°C) at both sites and higher at Moorepark (7.1°C) than at Solohead (6.1°C). In comparison with the 20-yr average, soil temperatures were approximately 0.4°C and 0.2°C above average at both Moorepark and Solohead, being 7.4°C and 6.7°C, respectively. In 2006, soil temperatures were close to average at Moorepark but below average at Solohead (5.6°C vs. 6.5°C).

***Grass production***

Grass DM yields increased with later harvest dates in both years (Table 2). There was no interaction between application date and application rate on any of the harvest dates in either year. In 2005, grass DM production declined significantly with later fertiliser N application dates at H1 ($P < 0.05$) and H3 ($P < 0.01$), but not at H2 ($P > 0.05$) and H4 ($P > 0.05$). In 2006, there were differences ($P < 0.01$) in grass DM production between application dates at H1 and H4, although the decline with later application date was not as clear-cut as in 2005. There was no difference ($P > 0.05$) in grass DM production between application dates at H2 and H3 in 2006.

Application rate had a significant ($P < 0.01$) effect on grass DM yield at every harvest in each year except H1 in 2006 (Table 2). In general, at H1 in 2005 grass yield increased with increasing rate of application. In contrast, at H1 in 2006 fertiliser N application had no significant effect on grass DM yields.

At H2 in 2005 there was a clear trend for grass yields to increase with fertiliser N input in the earlier of the combined applications: 60 + 0 and 90 + 0 compared with 0 + 60 and 0 + 90. The 60 + 0 application had higher ($P < 0.001$) yield than 30 + 30. There was no difference ($P > 0.05$) between 30 + 60 and 60 + 30, but both were lower ($P < 0.001$) than 90 + 0. All N-fertilised treatments had higher grass DM yields than the zero-N (0 + 0) treatment. A similar but less pronounced trend was recorded at H2 in 2006 with the zero-N treatment (0 + 0) producing a lower ($P < 0.01$) yield than those that were fertilised (0 + 90, 30 + 30, 30 + 60, 60 + 0, 60 + 30 and 90 + 0), with no difference in grass DM yields between the latter treatments.

In H3 in 2005 and 2006 there was a similar trend in grass yields to H2 with higher grass yields with increasing rates of fertiliser N in the earlier of the combined applications, but much less clear-cut in 2006 than in 2005. In H4 in both years

**Table 2:** The effects of fertiliser application rate, fertiliser N application date and harvest date (see Table 1) on grass dry matter (DM; kg/ha) production in spring 2005 and 2006

| Harvest date | H1 | | Harvest date | H2 | | H3 | | H4 | |
|---|---|---|---|---|---|---|---|---|---|
| Year | 2005 | 2006 | | 2005 | 2006 | 2005 | 2006 | 2005 | 2006 |
| **Application rate (R)** | | | **Application rate (R)** | | | | | | |
| 0 | 555 | 333 | 0 + 0 | 719 | 337 | 1,212 | 688 | 2,162 | 1,500 |
| | | | 0 + 60 | 785 | 365 | 1,727 | 924 | 3,112 | 2,263 |
| | | | 0 + 90 | 791 | 396 | 1,881 | 1,041 | 3,224 | 2,532 |
| 30 | 633 | 369 | 30 + 30 | 930 | 425 | 1,935 | 1,129 | 3,106 | 2,402 |
| | | | 30 + 60 | 989 | 417 | 1,964 | 1,206 | 3,361 | 2,551 |
| 60 | 653 | 368 | 60 + 0 | 1,025 | 465 | 1,785 | 1,138 | 2,956 | 2,384 |
| | | | 60 + 30 | 936 | 438 | 1,931 | 1,285 | 3,198 | 2,686 |
| 90 | 688 | 369 | 90 + 0 | 1,076 | 437 | 2,038 | 1,205 | 3,183 | 2,512 |
| s.e. | 18.9 | 13.6 | s.e. | 38.0 | 21.7 | 47.1 | 40.5 | 73.1 | 66.5 |
| **Application date (D)** | | | **Application date (D)** | | | | | | |
| D1 | 677 | 365 | D1 + D5 | 940 | 417 | 1,880 | 1,112 | 3,091 | 2,484 |
| D2 | 637 | 384 | D2 + D6 | 906 | 424 | 1,822 | 1,121 | 2,963 | 2,396 |
| D3 | 624 | 363 | D3 + D7 | 872 | 390 | 1,818 | 1,045 | 3,063 | 2,237 |
| D4 | 591 | 327 | D4 + D8 | | | 1,717 | 1,030 | 3,034 | 2,298 |
| s.e. | 18.9 | 13.6 | s.e. | 23.3 | 13.3 | 33.3 | 28.7 | 51.7 | 47 |
| **Level of significance** | | | **Level of significance** | | | | | | |
| Rate | *** | NS | Rate | *** | ** | *** | *** | *** | *** |
| Date | * | * | Date | NS | NS | ** | NS | NS | ** |
| R × D | NS | NS | R × D | NS | NS | NS | NS | NS | NS |

NS = non-significant.
*$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.

there was little difference in grass yields between treatments that received fertiliser N. At H4 averaged over all treatments receiving fertiliser N, there was an additional grass DM production response of 1,000 kg/ha in 2005 and 975 kg/ha in 2006 compared with the treatment that received no fertiliser N input (0 + 0).

In general, in 2005 and 2006, the split application of 60 kg/ha (30 + 30) resulted in higher grass DM production than, or was not different from, single applications of 60 kg/ha (0 + 60 and 60 + 0). The exception was at H2 in 2005 when 60 + 0 > 30 + 30. There were no detectable differences in grass DM production between 60 + 30 and 30 + 60 at each of the harvest dates in both years, except for H4 in 2005, when 30 + 60 > 60 + 30. The 30 + 60 treatment had higher grass DM production than 0 + 90 at H2 in 2005 and at H3 in 2006; otherwise, there were no differences between these two treatments. The 30 + 60 treatment had lower grass DM production than 90 + 0 at H2 in 2005; however, in contrast to this, 30 + 60 had higher grass DM production than 90 + 0 at H4 in 2005. There was no difference between these treatments at H3 in 2005 or at H2, H3 and H4 in 2006.

***Nitrogen uptake in grass***

Similar to grass DM yields, N uptake in grass DM increased with later harvest date in both years. There was no interaction between application date and application rate for any of the harvest dates in either year (Table 3).

There was a trend for N uptake to decline with later application date at H1 in 2005 ($P < 0.05$). At H1 in 2006 although N uptake was affected ($P < 0.05$) by application date there was no clear trend. In contrast to H1, N uptake was not affected by application date at any other harvest date in either year.

Application rate had a significant ($P < 0.001$) effect on N uptake at every harvest date in 2005 and 2006. At each of the harvests, plots that received fertiliser N had significantly greater uptake of N than the zero-N treatment. Similar to grass yields, differences between application rate treatments were more pronounced in 2005 than in 2006. At H1, N uptake

**Table 3:** The effects of fertiliser application rate, fertiliser N application date and harvest date (see Table 1) on N uptake in grass dry matter (kg/ha) in spring 2005 and 2006

| Harvest date | H1 | | Harvest date | H2 | | H3 | | H4 | |
|---|---|---|---|---|---|---|---|---|---|
| Year | 2005 | 2006 | | 2005 | 2006 | 2005 | 2006 | 2005 | 2006 |
| **Application rate (R)** | | | **Application rate (R)** | | | | | | |
| 0 | 24.7 | 13.5 | 0 + 0 | 26.3 | 14.7 | 42.0 | 23.3 | 58.2 | 44.2 |
| | | | 0 + 60 | 35.3 | 18.3 | 75.5 | 36.9 | 98.5 | 78.0 |
| | | | 0 + 90 | 38.2 | 20.4 | 88.8 | 44.5 | 109.0 | 92.9 |
| 30 | 31.0 | 16.2 | 30 + 30 | 42.3 | 21.4 | 80.7 | 43.8 | 94.5 | 80.7 |
| | | | 30 + 60 | 47.3 | 21.6 | 88.4 | 49.8 | 111.2 | 90.6 |
| 60 | 33.6 | 16.8 | 60 + 0 | 44.7 | 22.7 | 70.6 | 43.3 | 84.8 | 78.5 |
| | | | 60 + 30 | 44.5 | 22.8 | 83.6 | 52.0 | 100.7 | 92.6 |
| 90 | 36.2 | 17.0 | 90 + 0 | 49.5 | 22.1 | 84.7 | 48.0 | 97.9 | 85.6 |
| s.e. | 0.95 | 0.62 | s.e. | 1.71 | 1.12 | 1.76 | 1.70 | 2.33 | 3.00 |
| **Application date (D)** | | | **Application date (D)** | | | | | | |
| D1 | 33.5 | 16.0 | D1 + D5 | 42.6 | 20.8 | 78.2 | 43.4 | 94.3 | 84.2 |
| D2 | 31.7 | 17.1 | D2 + D6 | 41.1 | 21.3 | 76.0 | 44.5 | 92.8 | 81.1 |
| D3 | 31.3 | 16.2 | D3 + D7 | 39.4 | 19.4 | 78.1 | 41.7 | 94.8 | 76.8 |
| D4 | 28.9 | 14.4 | D4 + D8 | | | 74.8 | 41.3 | 95.6 | 79.5 |
| s.e. | 0.95 | 0.62 | s.e. | 1.05 | 0.68 | 1.56 | 1.24 | 1.82 | 1.95 |
| **Level of significance** | | | **Level of significance** | | | | | | |
| Rate | *** | *** | Rate | *** | *** | *** | *** | *** | *** |
| Date | * | * | Date | NS | NS | NS | NS | NS | NS |
| R × D | NS | NS | R × D | NS | NS | NS | NS | NS | NS |

NS = non-significant.
*$P$ < 0.05; ***$P$ < 0.001.

in grass DM simply increased with increased N fertilisation in both years.

At H2 in both years, there was a clear trend for N uptake in grass DM to be higher with increasing fertiliser N input in the earlier split of the combined application. This trend was somewhat diminished at H3 in both years, and by H4 in both years the highest rates of N uptake were associated with treatments that combined inputs of fertiliser N in both the earlier and later splits (30 + 60 and 60 + 30), or where a greater proportion of N was in the later split (0 + 90).

Uptake of N was higher for 30 + 30 than for 0 + 60 at H2 and H3 in both years, with no difference between these treatments at H4 in either year. In 2005, there was no difference between 30 + 30 and 60 + 0 at H2. In contrast, at H3 and H4 in 2005 30 + 30 had higher ($P$ < 0.001) N uptake than 60 + 0. In 2006, there was no difference between the latter application rate treatments at H2, H3 or H4.

There was no difference in N uptake between 30 + 60 and 60 + 30 at H2, H3 or H4 in 2006. Likewise, there was no difference in N uptake between 30 + 60 and 60 + 30 at H2 in 2005. At H3 and H4 in 2005, 30 + 60 had higher N uptake than 60 + 30. The 30 + 60 treatment had higher N uptake than 0 + 90 at H2 in 2005 and at H3 in 2006, with no difference between these treatments at the other harvest dates in each year. At H4 in 2005, 30 + 60 had higher N uptake than 90 + 0; otherwise, there were no differences in N uptake between these treatments at any of the other harvest dates in either year.

### *Apparent recovery of fertiliser nitrogen*

Averaged over both years, ARFN increased from 0.11 at H1 to 0.16 at H2 to 0.41 at H3 and to 0.54 at H4. However, the rates of increase with later harvest dates differed between years: ARFN was 0.17, 0.22, 0.52 and 0.54 in 2005 and 0.06, 0.09, 0.29 and 0.54 in 2006 for H1, H2, H3 and H4, respectively (Table 4). ARFN was not significantly affected by interaction between fertiliser N application rate and fertiliser N application date for any of the harvests in this study (Table 4).

**Table 4:** The effects of fertiliser application rate, fertiliser N application date and harvest date (see Table 1) on apparent recovery of fertiliser N (ARFN kg/kg of applied fertiliser N) in spring 2005 and 2006

| Harvest date | H1 | | Harvest date | H2 | | H3 | | H4 | |
|---|---|---|---|---|---|---|---|---|---|
| Year | 2005 | 2006 | | 2005 | 2006 | 2005 | 2006 | 2005 | 2006 |
| **Application rate (R)** | | | **Application rate (R)** | | | | | | |
| | | | 0 + 60 | 0.15 | 0.06 | 0.56 | 0.23 | 0.67 | 0.56 |
| | | | 0 + 90 | 0.13 | 0.06 | 0.52 | 0.24 | 0.57 | 0.54 |
| 30 | 0.21 | 0.09 | 30 + 30 | 0.27 | 0.11 | 0.65 | 0.34 | 0.61 | 0.61 |
| | | | 30 + 60 | 0.23 | 0.08 | 0.52 | 0.29 | 0.59 | 0.52 |
| 60 | 0.15 | 0.06 | 60 + 0 | 0.31 | 0.14 | 0.48 | 0.33 | 0.44 | 0.57 |
| | | | 60 + 30 | 0.20 | 0.09 | 0.46 | 0.32 | 0.47 | 0.54 |
| 90 | 0.13 | 0.04 | 90 + 0 | 0.26 | 0.08 | 0.47 | 0.28 | 0.44 | 0.46 |
| s.e. | 0.021 | 0.018 | s.e. | 0.024 | 0.018 | 0.026 | 0.023 | 0.030 | 0.040 |
| **Application date (D)** | | | **Application date (D)** | | | | | | |
| D1 | 0.21 | 0.04 | D1 + D5 | 0.25 | 0.08 | 0.55 | 0.29 | 0.38 | 0.51 |
| D2 | 0.13 | 0.07 | D2 + D6 | 0.20 | 0.12 | 0.51 | 0.35 | 0.68 | 0.62 |
| D3 | 0.18 | 0.08 | D3 + D7 | 0.21 | 0.07 | 0.52 | 0.24 | 0.6 | 0.49 |
| D4 | 0.14 | 0.05 | D4 + D8 | | | 0.51 | 0.29 | 0.51 | 0.55 |
| s.e. | 0.024 | 0.021 | s.e. | 0.016 | 0.012 | 0.032 | 0.023 | 0.035 | 0.037 |
| **Level of significance** | | | **Level of significance** | | | | | | |
| Rate | * | NS | Rate | *** | NS | *** | ** | *** | NS |
| Date | NS | NS | Date | * | ** | NS | ** | *** | NS |
| R × D | NS | NS | R × D | NS | NS | NS | NS | NS | NS |

ARFN = apparent recovery of fertiliser nitrogen; NS = non-significant.
*$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.

Application date had no significant ($P > 0.05$) effect on ARFN at H1 in either year or at H3 in 2005 or at H4 in 2006. Application date had a significant effect on ARFN at H2 in both years and at H3 in 2006 and at H4 in 2005. Where there were detectable differences between application dates the highest ARFN was associated with D2 + D6, with the exception of H2 in 2005 when it was D1 + D5.

Application rate had a significant impact on ARFN at all harvests in 2005: at H1 and H2, ARFN decreased with increasing N application rate; at H3 and H4, lower ARFN was associated with application rate treatments where a greater proportion of N was applied in the earlier split (60 + 0, 60 + 30, 90 + 0). In 2006, application rate had no significant effect on ARFN at H1, H2 and H4. At H3 in 2006 application rate had an impact ($P < 0.01$) on ARFN with split applications tending to have higher ARFN than early or later single N applications.

### *DM grass production and economic performance*

The second application date combination (D2 + D6) gave the best value for money and this was more clearly identifiable in 2005 than in 2006 (Figure 2).

Overall, the treatment that offered the best value for money in terms of additional grass DM grown as a consequence of fertiliser N application was the 30 + 60 treatment (Figure 3).

## Discussion

### *Date of application*

More often than not the date on which fertiliser N was applied had no significant effect on DM grass production (Table 2). Where an effect was detected the results were often conflicting with all four fertiliser N application dates having the potential to increase grass DM yield depending on year, site and rate of fertiliser N application. This is probably not surprising considering the differences in weather conditions between the 2 yr and the differences in soil type and elevation (50 vs. 150 m ASL) between the two sites. Other studies have also found a lack of a clearly identifiable optimum date for fertiliser N application in spring (Stevens *et al.*, 1989; Long *et al.*, 1991; Laidlaw *et al.*, 2000), which is in contrast to O'Donovan *et al.* (2004) who concluded, based on an experiment conducted at the Moorepark site, that

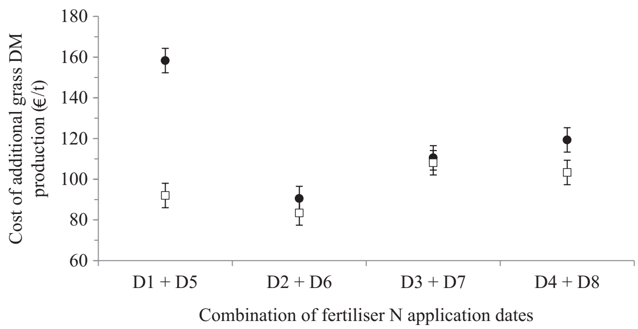


**Figure 2.** Economic cost (€/t DM) of grass harvested on 25 April following the application of fertiliser N on four date combinations (see Table 1) in 2005 (•) and 2006 (□). $P < 0.01$; error bar is ±s.e.

the optimum date for the application of fertiliser N in spring was in early January for the south-west of Ireland.

In the present study, there was a trend for earlier application dates to result in greater grass production at the earlier harvest dates during the milder spring of 2005, particularly at Moorepark. It is clear that weather conditions are responsible for the variable herbage production responses to fertiliser N application, which is likely to have impacted on grass growth and mineralisation rate of N in soil organic matter. In Ireland, fertiliser N in spring is often typically applied in anticipation of expected growth, which is based on average weather conditions and grass growth rates in previous years. Therefore, when looked at solely from the perspective of anticipated growth, it can often make sense to apply fertiliser N on an earlier application date (Humphreys, 2007). Since the introduction of the Nitrates Directive in Ireland in 2006, there is greater recognition of the need to limit N losses from the production system. In the present study, ARFN at H4 indicated the extent of N uptake in grass DM (Table 4) and in 2005 the earliest date combination had the poorest ARFN while the second date had the highest. There was a similar trend at H3 in 2006, whereas application date had no significant effect on ARFN at H4 in 2006. This is also reflected in the economic response to fertiliser N, where the most cost-effective option was the application of fertiliser N on the second application date combination (21 January and 26 February; Figure 2), particularly in 2005. In this instance, there was good agreement between cost-effectiveness and ARFN.

Part of the reason for the poorer ARFN with the later application date application combinations (D3 + D7 and D4 + D8) was due to later application dates; probably not all of the applied fertiliser N had been taken up by the crop by the time of the final harvest on 25 April (H4). It is likely that if the timeframe of this study was extended beyond 25 April, higher ARFNs would have been recorded for the later application date combinations similar to that recorded by Murphy *et al.* (2013). However, such considerations are outside the scope of this study, which was focused on the timeframe between 21 February and 25 April, which approximately coincides with the typical calving interval of spring-calving herds in Ireland when cows are turned out to pasture after calving. The economic consideration in the present study is the feed and other costs associated with keeping cows indoors on grass silage and concentrates or turning the cows out to grazed grass. O'Donovan *et al.* (2011) put a cost on grass silage of €183/t of utilisable DM and €230/1,000 UFL and concentrate cost in recent years averaged €325/t DM (assuming 85% DM content) according to CSO (2018). The costs of these alternative feeds are substantially higher than the cost of additional grass grown as a consequence of fertiliser N application (Figures 2 and 3). This comparison does not account for the poorer nutritive value of grass silage compared with grazed grass in spring or the other costs of keeping cows indoors such as cost of feeding, bedding and slurry application. In the present study, it is clear that the application of fertiliser N in spring offered a substantially lower cost option for feeding dairy cows within the timeframe relative to alternatives, regardless of the fertiliser N application date and application rate treatments imposed. However, of the application date treatments imposed the second application date combination (21 January and 26 February) was probably the best option in terms of cost-effectiveness and ARFN.

### *Rate of application*

In general, the biggest differences in grass DM yields were between treatments that had received fertiliser N and those that did not, and this was evident across all harvest dates, including the earliest harvest date (H1). In general, there was no difference in grass yields between applications of 30, 60 or 90 kg/ha. The exception to this was H2 in 2005, when the earlier applications at higher rates (60 and 90 kg/ha) gave a higher grass production response compared with treatments where 30 kg/ha was applied at that stage of the experiment. On the other hand, earlier applications at higher rates tended to be lower yielding at later harvest dates, particularly in 2005. Furthermore, ARFN tended to be higher with lower rates of application, for later application dates and for split applications 30 + 30 and 30 + 60.

The timeframe of the harvests in this experiment was set up to coincide with the first grazing rotation on a typical dairy farm. From late April onwards, grass growth generally exceeds demand for grazed grass and this excessive supply means that grazed grass becomes relatively less valuable throughout the spring; that is, it no longer has the same value relative to grass silage and concentrates as described above. On this basis, it can be argued that additional grass at H1 was more valuable than additional grass at H4. It is also likely that a deficit in supply of grazed grass can occur at any stage during the first

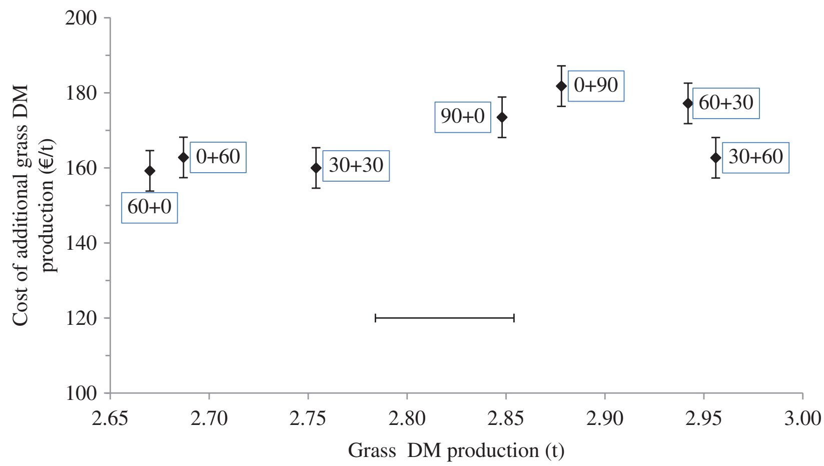


**Figure 3.** Grass dry matter production and the cost of growing the additional grass (€/t DM) above that produced with no fertiliser N input. Vertical error bars are ±s.e. for costs (€/t DM) and the horizontal error bar is the s.e. for grass DM production.

grazing rotation, depending primarily on the impact of weather conditions on grass growth, which are very variable from year to year (Figure 1). Indeed a shortage of grazed grass can often be most acute and problematical towards the end of the first grazing rotation in years with poorer grass growing conditions within this timeframe. Hence, for simplicity grazed grass is valued equally within the timeframe of this experiment. The additional grass harvested at H4 was accumulated during the timeframe of the experiment and, hence, the cost of additional grass DM produced is taken as indicative of each treatment (Figure 3). In general, the split applications of fertiliser N (30 + 30 and 30 + 60) were the most cost-effective treatments for the quantity of applied fertiliser N (Figure 3).

## Conclusions

Grass DM production increased with higher input of fertiliser N. Split applications (30 + 30 and 30 + 60) tended to produce higher grass DM production than single applications for both levels of fertiliser N input (60 and 90 kg/ha) in this study. Split applications also tended to result in higher ARFN than single applications. The optimum date to commence fertiliser N application was 21 January combined with a second application on 26 February in terms of the cost-effectiveness of the fertiliser N input to increase grass DM production. Earlier application dates increased grass DM production when conditions were suitable. On the other hand, earlier application dates resulted in a poor grass DM production response when conditions were not suitable and were also associated with lower ARFN. Taking into account the variability in weather and spring grass growing conditions from year to year, a low level of fertiliser N input (30 kg/ha) is recommended in early spring when the risk of losses is high. This should be followed by a second application later in the spring when there is likely to be higher recovery of applied fertiliser N and a higher grass DM production response.

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