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Urine patch distribution under dairy grazing at three stocking rates in Ireland

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Nitrate pollution of water is a serious global environmental issue. Grassland agriculture is a major source of diffuse nitrate pollution, with much of this nitrate originating from the urine patches of grazing animals. To study nitrate losses from grassland it is necessary to consider the areas of grassland that are affected by urine separately from the remainder of the pasture. Urine patches can be observed in the field as areas of vigorously growing pasture, however the pasture may continue to respond for several months, making it difficult to determine when the observed patch was actually deposited. A global positioning system was used to record the location of all urine and dung patches in a pasture at every second grazing on an Irish dairy farm during the grazing season. Any patches reappearing were removed from the data, allowing the fresh urine patches to be identified. Dairy cows deposited 0.359 urine patches per grazing hour, a value that may be used to predict the distribution of urine patches under any grazing regime. This equated to 14.1 to 20.7% of the soil surface being wet by urine annually at stocking rates of 2.0 to 2.94 cows per hectare, consistent with previous research. These values may be used in conjunction with values for nitrate loss from urine and non-urine areas to calculate nitrate losses from grazed pasture at a range of stocking rates.

Keywords: dairy cows; grazed pasture; stocking rate; urine distribution

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Introduction

Nitrate pollution of water is a global environmental problem. Nitrate can contribute to the eutrophication of surface waters and marine environments (Stark and Richards 2008), and high levels in drinking water may also cause methaemoglobinaemia in formula-fed infants (World Health Organization 2006).

Grazed-grassland agriculture is a significant source of diffuse nitrate pollution (Jarvis, Scholefield and Pain 1995). Urine deposited by grazing animals is a particularly important source of nitrate, as it adds a high concentration of N (equivalent to up to 1,000 kg/ha) at one point in time to a small area of soil (0.16 to 0.49 m^2 for cattle; Haynes and Williams 1993). As a result, the N losses from urine patches are far greater than from other areas of the sward (Di and Cameron 2002a). To accurately study the movement of N in a grazed soil, areas of soil that have or have not received urine must be considered separately.

A number of researchers have reported the size of a single cattle urination (Haynes and Williams 1993). Urine patches are often visible as areas of darker green, vigorously growing pasture. However, the area of pasture that responds to urine application may be much larger than the area that was actually wet by urine (Nguyen and Goh 1994), due to lateral movement of nutrients via soil and roots. Most researchers have measured the area of pasture response (Petersen, Lucas and Woodhouse 1956; Lotero, Woodhouse and Petersen 1966; Richards and Wolton 1976; Lantinga *et al*. 1987; Moir *et al.* 2011), some have measured the area wet by urine (Williams, Gregg and Hedley 1990; Williams and Haynes 1994), and some have reported both (Doak 1952; Nguyen and Goh 1994). However, urine patch areas have often been published without any description of the calculation methodology used (e.g., Davies, Hogg and Hopewell 1962; Robertson 1972; Jarvis *et al.* 1995). From the literature that specifies the calculation method used, the mean area of a urine-wet patch was 0.33 m^2 of soil surface (range 0.16 to 0.49 m^2), whereas 0.81 m^2 of pasture (range 0.28 to 3.53 m^2) was affected by a urine patch. When studying soil processes, the area of soil actually wet by urine is likely to be more relevant than the area of pasture response. Unfortunately this is more difficult to determine in the field.

Some researchers have attempted to quantify the area of a pasture affected by urine annually. Petersen *et al*. (1956) and MacLusky (1960) recorded the number of dung patches in a pasture and, assuming that there were the same number of urine patches deposited, predicted the annual area of pasture affected by urine. However, it is arguable whether the distribution of urine and dung are in fact identical, and therefore it would be better to measure urine patches directly. Urine patches deposited in different seasons result in the leaching of different quantities of nitrate (Di and Cameron 2002b). Therefore, when calculating nitrate losses it is important to determine not only the total area of soil receiving urine annually, but also the seasonal distribution of urine deposition.

Richards and Wolton (1976) measured the pasture response area and number of cattle urinations visible on a pasture following a single grazing, and calculated the annual area of coverage by urine based on the assumption that urine patches may remain visible for 3 months and then disappear, an assumption that is widespread in the literature (e.g., Haynes and Williams 1993). However urine patches may still be visible 11 months after deposition, and can even disappear for several months then reappear (Dennis 2005; Dennis, Moir and

Cameron 2007c). It is impossible to know how many of the urine patches observed after one grazing by Richards and Wolton (1976) were actually deposited during that grazing, and how many had reappeared from previous grazing periods.

Direct observation of every urination event has been conducted and is precise (White *et al*. 2001), however this is very labour-intensive and the presence of observers could change natural cattle behaviour. Furthermore, for practical and financial reasons, direct observation could only be conducted on a few days in the year and may not represent the true mean urination frequency. For this reason, data on actual coverage by urine from grazing animals are scarce and are required for the modelling of the fate of N deposited to pasture by grazing animals.

To overcome these problems, Moir *et al*. (2006, 2011) used a real time kinematic global positioning system (RTK-GPS) to record the precise location of all urine patches observed in the field every 12 weeks. This allowed urine patches that were reappearing from previous grazing periods to be identified and eliminated, ensuring that only fresh urine patches were counted. A variation of this method was used in this trial as it is the most accurate way of recording spatial distribution without resorting to labour-intensive manual observation. It was hypothesised that the spatial and temporal distribution of urine is related to grazing intensity.

Materials and Methods

The methodology employed has been described by Dennis *et al*. (2007a,b, d). The present study was undertaken in 2007 within a 3-year grazing experiment (2007 to 2009) at the Teagasc, Animal and Grassland Research and Innovation Centre, Moorepark, Fermoy, Co. Cork, Ireland (50°07′N, 8°16′W; 46 m above sea level). The grazing experiment involved 3 stocking rates, 2.0, 2.47 and 2.94 livestock units (LU; 1 cow = 1 LU) per hectare, and 3 fertilizer N levels within each stocking rate (Table 1), resulting in a total of 9 treatments. There were 5 cows per treatment, and each treatment had its own individual farmlet. The land area of each farmlet was adjusted to account for the differences in stocking rate. Each farmlet was divided into 3 equal sized paddocks (0.833 ha for 2 LU/ha, 0.675 ha for 2.47 LU/ha and 0.567 ha for 2.94 LU/ha). Two of the 3 paddocks had silage harvested from them during the grazing season and were available for grazing outside of silage periods. Each paddock was further sub-divided into 4 equal areas, using temporary electric fencing, and these paddock quarters were rotationally grazed with residencies of 2 to 6 days, depending on time of year and pre-grazing herbage mass. Cows were turned out to grass on all treatments on 10 February and grazing ceased on the 20 November 2007; cows were housed through the winter months. During the grazing season, cows spent approximately 21 h/day on the pasture, and 3 h/day walking to and from the milking parlour and being milked. Animals on treatments with the same stocking rate had the same residency time in each grazing area, regardless of fertilizer N application rate. As a result the post-grazing pasture heights were 5.5, 5.9 and 5.9 cm at the low, medium and high N rates (averaged across stocking

Table 1. Grazing treatments, N fertilizer application rates and land area per treatment

Stocking rate (cows/ha)	Fertilizer N (kg/ha)			Land area (ha) per farmlet
2.0	119	160	193	2.50
2.47	147	196	205	2.02
2.94	172	221	229	1.70

rates). Paddocks were topped twice during the summer. The dates when paddock quarters were grazed are shown in Table 2 and dates of N fertilizer application are in Table 3.

Two plots (each 10 m × 10 m) per treatment (6 plots per stocking rate) were established, one in each of the first 2 quarters of the paddocks not harvested for silage. These areas are hereafter referred to as the trial plots. Urine and dung patch measurements were made in these areas only.

The treatment stocking rate was calculated over all 3 paddocks in each treatment; however, in practice, the cows spent less time on the 2 paddocks from which silage was harvested, and more on the paddocks containing the trial plots, making the effective stocking rate on the trial plots higher than the treatment stocking rate.

Urine and dung patches were visually identified at the start of the trial, and for every second grazing thereafter from February 2007 to March 2008. Urine patches were identified based on pasture growth response 15 days post grazing. In practice measurements were taken *ca.* 15 days after cows left the second paddock quarter. The location of the centre of each patch was recorded using a survey grade RTK-GPS unit (Trimble, California, USA).

Since all autumn-deposited urine patches may not be visible in autumn, and may only appear in spring (Dennis *et al*. 2007c), the final measurement was taken in March 2008, before first grazing. Because it was difficult to identify patches visually at this time of year, the plots were mown in February 2008, and patches were observed after 3 weeks of regrowth. Each time a paddock quarter was grazed, the number of cows grazing the quarter was recorded (the number deviated from 5 cows in spring (February to early April) and autumn (late October and November), depending on individual calving and dry-off dates), along with the date and grazing duration. A urine patch was only considered to be fresh if it was not within 15 cm of a urine or dung patch that had been observed within the previous two observation periods. All urine patches that were observed within 15 cm of a dung or urine patch recorded in the previous two observations were considered to represent a pasture growth response from the old dung or urine patch, not a fresh patch. These patches were identified individually using ArcGIS 9.3 (ESRI 2008), and were removed from the data along with all dung patches, leaving only the fresh urine patches. Both the grazing data and the urine patch distribution were classified by observation date throughout the year, to identify the grazing period associated with the urine patches in each observation. There was no grazing between the observations made in December and March.

Data were analysed using linear models in R (R Development Core Team 2008). Data distributions were evaluated for normality using the Shapiro-Wilk normality test and visual inspection of residual plots. The annual and seasonal effects of stocking rate (defined as hours at pasture) and fertilizer N application rate on the frequency of urine patch deposition were tested using linear modelling ("lm" function of R). The fertilizer N rate, stocking rate and their interaction were included in the model as fixed effects. Each 10 m×10 m plot was considered to be an experimental unit.

Results

Stocking intensity

The total annual grazing time expected at each of the nominal stocking rates are presented in Table 4, and were calculated assuming that 21 cow-grazing hours equals 1 grazing day and 283 grazing days

Table 2. Periods when cows were resident in study area and total number of grazing days (21 h) during residency period

Stocking rate	Paddock quarter	Cows in paddock quarter		Total cow-grazing days
		Number	Period	
2	1	2	1 Mar–15 Mar	8.00
		3	15 Mar–16 Mar	5.00
		5	29 Apr–6 May	33.33
		5	31 May–3 June	15.00
		5	22 June–25 June	15.00
		5	25 July–1 Aug	30.00
		5	14 Sept–21 Sept	35.00
		4	8 Nov–16 Nov	32.00
	2	4	16 Mar–24 Mar	26.66
		5	6 May–15 May	45.00
		5	3 June–7 June	20.00
		5	25 June–27 June	10.00
		5	1 Aug–5 Aug	20.00
		5	26 Sept–29 Sept	20.00
		5	8 Oct–12 Oct	20.00
		4	16 Nov–19 Nov	12.00
2.47	1	2	1 Mar–15 Mar	8.00
		3	15 Mar–16 Mar	5.00
		5	29 Apr–6 May	33.33
		5	31 May–4 June	20.00
		5	22 June–24 June	10.00
		5	24 July–28 July	21.70
		5	16 Aug–19 Aug	10.00
		5	26 Sept–3 Oct	35.00
		4	7 Nov–10 Nov	12.00
	2	4	16 Mar–24 Mar	26.66
		5	6 May–12 May	30.00
		5	4 June–7 June	15.00
		5	24 June–25 June	6.66
		5	28 July–4 Aug	33.33
		5	19 Aug–21 Aug	8.33
		5	3 Oct–6 Oct	15.00
		4	10 Nov–14 Nov	16.00
2.94	1	2	7 Mar–8 Mar	1.33
		3	9 Mar–15 Mar	8.00
		5	30 Apr–3 May	20.00
		5	31 May–4 June	20.00
		5	22 June–23 June	5.00
		5	8 July–10 July	10.00
		5	31 July–5 Aug	23.33
		5	24 Aug–29 Aug	25.00
		5	23 Sept–25 Sept	10.00
		4	7 Nov–9 Nov	8.00
	2	4	16 Mar–19 Mar	10.66
		5	4 May–8 May	20.00
		5	5 June–8 June	18.33
		5	23 June–25 June	11.65
		5	10 July–12 July	10.00
		5	5 Aug–8 Aug	15.00
		5	10 Sept–14 Sept	20.00
		4	9 Nov–16 Nov	28.00

Table 3. Dates and rate of fertilizer N application to trial plots

Treatment combination		Fertilizer details†		Total N (kg/ha)
Stocking rate (cows/ha)	Fertilizer N (kg/ha)	Date	N applied (kg/ha)	
2	165	07/04/07	28	
		16/05/07	33	
		18/06/07	16.5	
		16/07/07	16.5	
		22/08/07	24.75	118.75
	205	07/04/07	28	
		16/05/07	33	
		18/06/07	16.5	
		16/07/07	16.5	
		22/08/07	33	
		08/09/07	33	160
	245	07/04/07	28	
		16/05/07	33	
		18/06/07	33	
		16/07/07	33	
		22/08/07	49.5	
		08/09/07	33	209.5
2.47	205	07/04/07	56	
		16/05/07	33	
		18/06/07	16.5	
		16/07/07	16.5	
		22/08/07	24.75	146.75
	245	05/04/07	56	
		16/05/07	33	
		13/06/07	24.75	
		14/07/07	16.5	
		09/08/07	33	
		11/09/07	33	196.25
	285	07/04/07	56	
		16/05/07	33	
		06/06/07	33	
		16/07/07	33	
		22/08/07	49.5	204.5
2.94	245	05/04/07	56	
		16/05/07	33	
		13/06/07	33	
		14/07/07	33	
		21/08/07	16.5	171.5
	285	05/04/07	56	
		16/05/07	33	
		18/06/07	33	
		14/07/07	33	
		22/08/07	49.5	
		08/09/07	16.5	221
	325	05/04/07	56	
		18/05/07	33	
		13/06/07	33	
		14/07/07	33	
		21/08/07	33	
		08/09/07	41.25	229.25

†Applied in the form of urea at the first application date for each treatment combination and as calcium ammonium nitrate at all other dates.

Table 4. Total annual grazing time for each stocking rate

	Stocking rate treatment (cows/ha)		
	2.00	2.47	2.94
Predicted† annual cow-grazing hours (h/ha)	11886	14679	17472
Actual annual cow-grazing hours (h/ha)	18010	19674	19429
Actual stocking rate (cows/ha)	3.03	3.31	3.27
Urine patches observed (number/ha)	5517	7167	7933
Area covered by urine (%)	18.2	23.7	26.2
Predicted† area covered by urine (%)	14.1	17.4	20.7

†Based on stocking rate treatment.

per year (10 February to 20 November). Due to the silage harvesting regime, the actual stocking rates were higher on the trial plots. The actual cow-grazing hours recorded on the trial plots are also in Table 4 along with the corresponding calculated values for cows per hectare using the same assumptions as above.

Annual distribution of urine deposition

The total annual number of fresh urine patches per hectare, as a function of cow-grazing hours, is shown in Figure 1. The number of urine patches increased with stocking rate ($P=0.015$, $R^2=0.39$). Fertilizer N rate did not affect the number of urine patches ($P=0.18$).

The number of urine patches recorded at each observed stocking rate is shown in Table 4 as is the proportional area covered by urine for each stocking rate treatment assuming that the average area covered by urine was 0.33 m^2 per urine patch. The number of urine patches that would be deposited over a farm grazed at each of the three treatment stocking rates and the

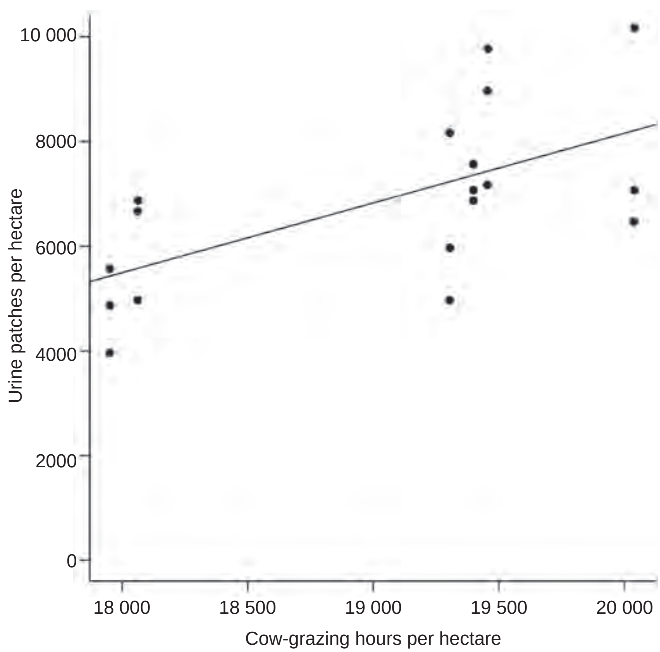

Figure 1. Relationship between the number of urine patches (Y) and total cow-grazing hours (X) (Y=−1849+1.332X).

corresponding proportional area covered by urine are also shown in Table 4. These were calculated from the overall mean number of urine patches deposited per cow-grazing hour (0.359) and the expected grazing hours per stocking rate.

The mean, across all treatments, number of urine patches deposited per cow-grazing hour was 0.359 and the corresponding annual number of urine patches deposited was 6,872/ha. Assuming an average area of 0.33 m^2 for each urine patch, the mean annual proportion of the area covered by urine was 22.7%.

Seasonal distribution of urine deposition

The number of fresh urine patches observed per plot at each observation time point is shown in Figure 2 along with the mean cow-grazing hours that preceded each observation time.

Few urine patches were observed on the 14 May. This observation was made too soon following grazing, an error that was realized at the time. A second observation was therefore made on the 22 May at which time more fresh patches were detected. The fresh urine patches recorded at these two observation times were combined for ease of interpretation. Particularly high numbers of patches were observed in August 2007 and March 2008.

The number of fresh urine patches per plot observed at any one date was not explained by the length of the grazing period since the last observation (P=0.39), nor was there any evidence for an effect of fertilizer rate (P=0.15). The number of fresh urine patches observed was purely a

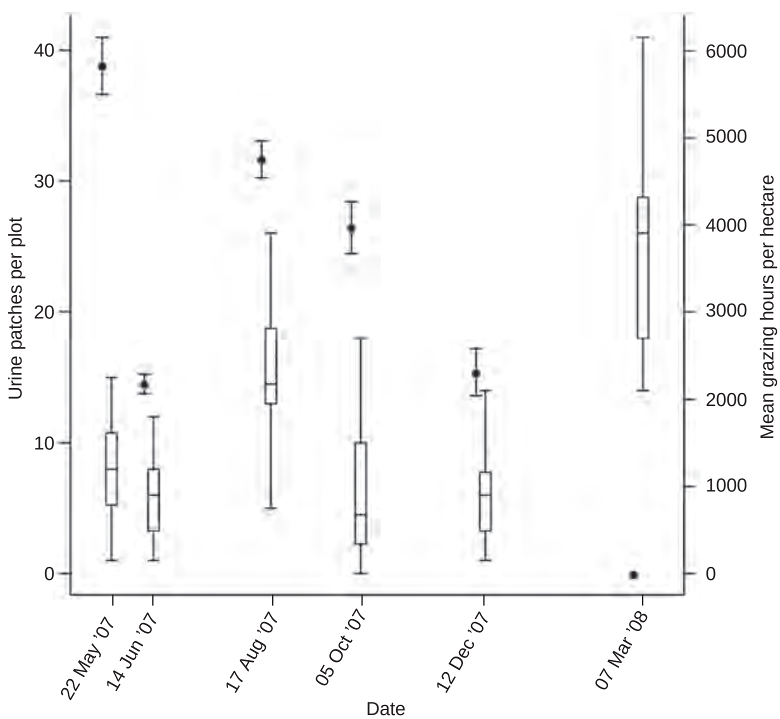

Figure 2. Number of urine patches per plot (100 m^2) at each observation time point (box-plot), and the mean number of cow-grazing hours preceding each observation (•; vertical bars=±s.e.).

function of observation date (P<0.001). Even when only the observations from June to December were analysed, when grazing hours appear to be correlated with number of patches (Figure 2), there was still no evidence for an effect of grazing hours (P>0.05).

Discussion

The observed data are representative of urine distribution within the grazing-only part of a two-cut silage system. They do not represent the mean distribution of urine patches across an entire farm.

The mean deposition frequency of urine patches per cow-grazing hour can be used to calculate the expected urine patch distribution under any grazing regime, and equates to 7.55 urine patches per grazing day given that there were 21 grazing hours per day. The literature on cows indicates 8 to 12 urinations per day (Petersen *et al*. 1956; Davies *et al*. 1962; Whitehead 1970; Robertson 1972; Nguyen and Goh 1994; Jarvis *et al*. 1995; White *et al*. 2001; Aland, Lidfors and Ekesbo 2002). Since the cows in the present study spent 3 h per day off the paddock for milking, and cows have a tendency to urinate during milking (Aland *et al.* 2002) the observed patch numbers are consistent with the literature.

Oudshoorn, Kristensen and Nadimi (2008) observed 0.26 urinations per hour during grazing, or 6.5 urinations per cow per day. This is lower than in most reports in the literature, and lower than recorded in the present study. The cows in Oudshoorn *et al*. (2008) were at pasture for a maximum of 9 h per day, unlike the current trial where cows were predominately at pasture. In addition, these observations were only conducted while the cows were grazing during the daytime, while cows commonly urinate and defecate more frequently where they lie down for the night (Castle and Halley 1953), which could have reduced the frequency of urination observed by Oudshoorn *et al*. (2008). However, urinations appear to have only been recorded in the field, which was a small fraction of the day. The cows in Oudshoorn *et al*. (2008) may have been urinating more frequently in the barn, reducing the number of urinations in the field, potentially due to differences in the stress level, temperature or diet of the cows in each location. However, as figures for urination frequency in the barn have not been published this is difficult to determine. The value of 0.359 urine patches per grazing hour recorded in the current trial is more consistent with other literature than the value reported by Oudshoorn *et al*. (2008). Moir *et al.* (2011) recorded 0.30 urine patches per cow-grazing hour, similar to the value recorded in the current study.

The mean annual proportion of the area covered by urine (22.7%) is similar to the 23.2% coverage for New Zealand dairy pasture that Moir *et al*. (2011) recorded over 4 years using similar methodology. This result is also comparable with the value of about 20% reported by other authors (MacLusky 1960; Richards and Wolton 1976; Whitehead 2000).

The lower percentage area covered calculated for the intended stocking rates of 2.00, 2.47 and 2.94 LU/ha (Table 4) are comparable to those observed by Moir *et al*. (2006) on a New Zealand sheep and beef farm (14.3 to 19.3%), with 15.1 NZ standard stock units (1 sheep plus 1 lamb) per hectare. This is equivalent to around 1.7 dairy cows per hectare, if cows were grazed permanently on the pasture like the sheep and beef livestock, or around 1.9 cows per hectare when an absence of 3 h per day for milking is assumed.

Urine patch number was shown to be purely a function of stocking rate, and unrelated to N fertilizer input. Fertilizer

N application rate may have influenced N concentration in urine but this was not measured. Higher N fertilizer inputs may cause higher pasture growth, which could result in both increased stocking rate and number of urine patches, but this effect could not be examined in the current trial as stocking rates were fixed for the purposes of the grazing experiment in which these measurements were undertaken.

The seasonal data (Figure 2) demonstrate the difficulty in determining the seasonality of urine deposition through field observations. Although total grazing time was correlated with annual urine patch deposition (Figure 1), this correlation was not observed in the seasonal data (Figure 2). Fewer urine patches were observed at the initial May observation than might have been expected from the high values for cow-grazing hours prior to that observation (Figure 2). Conversely, at the final March observation many fresh urine patches were observed, despite there having been no grazing since the previous observation. Moir *et al.* (2011) recorded fewer urine patches, on average, in winter than in other months, although the trend varied between years and was less pronounced than in the present study.

It appears that a number of the urine patches deposited in May may not have caused a pasture growth response until later in the year, if at all. In addition, it appears that many urine patches deposited in autumn did not generate a response in time to be recorded in October or December, but were evident the following spring. This is consistent with the observations of Dennis *et al*. (2007c), that urine patches may not generate a response immediately after deposition, but a response may appear a month or more later. They also observed urine patches yielding a poor response in autumn but appearing in spring, and patches that had been deposited during the summer disappearing over winter before reappearing in spring. During and McNaught (1961) also observed a response on urine patches for 1 year following deposition.

Given that the seasonal data may not reflect the actual seasonal distribution of urinations, it is most practical to assume a constant urination frequency over the year and calculate seasonal urine distribution on that basis. There are not enough data in the literature to determine whether urination varies over the year; the results from the most relevant study (Aland *et al.* 2002) showed that urination frequency varied with age (heifers *vs*. cows) but did not vary with milk yield or feeding intensity, although there was considerable unexplained variation. Therefore, it is reasonable to assume that urination frequency does not vary over the year until there is evidence to the contrary.

This delay between deposition and response makes the seasonal data unsuitable for predicting the number of urine patches in each season. However, the annual data allow the total urine patch distribution over the year to be calculated, and this may be used to predict the seasonal distribution assuming a constant urination frequency.

Conclusions

The value for urine deposition, in conjunction with values for N loss from urine-patch areas and non-urine areas, can be used to calculate N loss from grazed grassland at any stocking rate and under any grazing regime. Dairy cows, grazed at stocking rates of 2.0 to 2.94/ha, wet 14.1 to 20.7% of the soil surface with urine annually.

Since the actual stocking rate, and therefore the seasonal distribution of urine patches, may vary among different areas of a farm, due to practices such as silage harvesting, corresponding variation is to be expected in the potential for N loss. The evidence for a delay in pasture growth response following urine deposition must be considered in any future work involving the observation urine patches in the field.

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