THE COWS ROLE IN REDISTRIBUTING N AROUND THE DAIRY FARM

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Abstract

Intensification and scale of production are increasing in the livestock industries in New Zealand. This could lead to negative environmental impacts due to increased fertiliser inputs and runoff, and consequent increased return of animal excreta to water. Of particular concern in New Zealand is the high level of nitrogen (N) pollution arising from dairy farms due to the inhomogeneous nature of bovine urine patches. This study aimed to provide baseline knowledge on the distribution of urine by dairy cows in regard to environmental and management factors. Seventeen cross-bred dairy cows in late lactation, in a herd of 180, were fitted with global positioning system (GPS) collars, IceTag3D® activity sensors and urine sensors for seven consecutive days. The herd was milked twice a day and rotationally grazed, without supplements. Animals were at pasture from 06:00 h to 14:00 h (AM grazing) and from 15:00 h to 05:00 h (PM grazing). Cows were rotated through 12 paddocks of ~1.1 ha. The majority of urine (85% of total) was deposited on pasture, while 10% of total urine deposits were captured in the holding yard and milking shed (5%). Kernel density estimates showed that urine patch distribution was inhomogeneous, thus there was an aggregation of urine patches within specific areas of the paddocks. Moderate correlations between the time spent in a location and urine patch density provided preliminary evidence that the time spent in a particular location was the main factor affecting the density of urine patches. Paddock characteristics did not play a major role in determining urine distribution patterns in this study. Understanding excreta distribution may have application in farm management strategies aimed at managing loss of nutrients and pasture utilisation.

Introduction

New Zealand farmers are facing increasing pressure to reduce nutrient losses from their farming enterprises to the environment caused by grazing ruminants (Ledgard, 2001). Research suggests that the major source of nutrient loss are animal excreta (e.g. Legard, 2001; Di and Cameron, 2002; Monaghan *et al.*, 2007), which for nitrogen (N) relates to cattle urine in particular (Di and Cameron, 2007). Most models used to describe N cycling and predict loss assume homogeneous distribution of urine patches across the paddock (Wheeler *et al.*, 2008; Schoumans *et al.*, 2009). However, non-uniform distribution (e.g. stock camping) is well known and can be caused by several environmental factors (Petersen *et al.*, 1956; Stuth, 1991; Franzluebbers *et al.*, 2000; White *et al.*, 2001), and on dairy farms particularly, around gateways (Matthew *et al.*, 1988; McDowell, 2006). Heterogeneous urine distribution results in higher localised rates of N application (kg N/ha) than if the same amount of urine was evenly distributed over the paddock. Losses from stock camps will also be higher due to the greater probability of overlapping urine patches and consequent exponential rise in the rate of N leaching due to higher soil N loading (Pleasants *et al.,* 2007; Shorten and Pleasants, 2007). These localized areas receive higher deposits of N than the average for the paddock (Eriksen and Kristensen, 2001; White *et al.,* 2001; McGechan and Topp, 2004) and could be of particular environmental consequence during times of low plant N uptake (McGechan and Topp, 2004).

This study aims to provide base-line knowledge of how dairy cows (*Bos taurus*) distribute urine in regard to several environmental factors. Understanding the distribution of urine may allow the development of management practices that target critical source areas (CSAs) of N leaching, for example the targeted application of nitrification inhibitors to N-leaching hotspots within a paddock as opposed to broadcast application across the whole paddock. Such knowledge will also help farmers develop more accurate nutrient budgets and plan precise, variable rate fertilizer applications by taking into consideration a possible non-homogeneous urine distribution.

The objectives of this study were to:

1. Observe the temporal and spatial urination behaviour of dairy cows on a commercial farm.
2. Quantify spatial patterns of urination density within grazed paddocks.
3. Investigate potential relationships between urination density and physical properties of the grazed paddocks.

Methods

The study took place on Dairy No.4 at Massey University, Palmerston North, New Zealand (41°18′5.61″S 174°46′31.88″E) during early autumn in March 2009. The animals were managed outdoors in a rotational grazing system and no supplements were fed during the trial. Thirty cows were selected from the herd based on position in the herd at milking (i.e. milking order) and age. The herd of 180 cows was established 10 days prior to observation and its composition was kept constant. No animals were added to or removed from the herd for 10 days prior to commencing observations. Selected cows were electronically monitored for seven consecutive 24 h periods during March 2009. The average times of sunrise and sunset were 07:15 h and 19:45 h respectively. All animal experimentation was carried out following approval by the Massey University Animal Ethics Committee (Protocols 08/06 and 08/53).

Animal measurements

Thirty cows that were selected for the study were fitted with GPS units. The GPS units were custom-made using Trimble® Lassen GPS modules programmed to allow for continual tracking of satellites and logging of animal positions. Twenty four cows, of the thirty study cows, were also fitted with urine sensors (AgResearch and Enertol Ltd.). The urine sensor is independent of the GPS unit and has its own power supply in a form of a 3.6 V N-type battery. It comprises a hormone-free modified CIDR® device where the stem has been removed and replaced with a 100 mm long acrylic, threaded pipe within which the battery and electronics are placed. A 60 cm long silicon tube is attached to the distal end of the pipe within which a cable is attached with a thermistor at its terminal end. The wings of the CIDR® anchor the urine sensor within the cow's vagina. The silicon tube has several holes at the upper end to allow urine to enter, pass over the thermistor, and drain to the ground. The urine sensor works on the principle of detecting urination events by monitoring the rise from ambient temperature to near body temperature as the urine passes over the thermistor. The temperature is monitored every second and where the output deviates by 1ºC (≥2mV) from the previously logged data value, the record is saved by the device with its corresponding time (Betteridge *et al.,* 2010b). The approximate location of an urination event is generated by matching the time of the recorded urination event with GPS time. The merged datasets were used to generate a GIS layer of urination locations in space and time. Urine sensor validation is described by Betteridge *et al.* (2010b).

Paddock measurements

Pasture cover was measured prior to each grazing using the C-Dax Pasturemeter®. The Pasturemeter is pulled behind an All Terrain Vehicle (ATV) and can be used at speeds of up to 20 kmh^{-1} (Lawrence *et al.,* 2007). The ATV was driven across each paddock along parallel, regularly spaced tracks. A GPS has been incorporated with the Pasturemeter providing information on the position of collected readings in space and time. The GIS layer was generated using a spatial prediction method called kriging (ArcMap Version 9.3, ArcGIS 9, USA). This method interpolates the value of a random field, at an unobserved location, from observations of its value at nearby locations using a spherical model (Haining, 2003).

A pre-existing digital elevation model (DEM) (New Zealand Centre for Precision Agriculture, 2009) was used to create GIS layers of slope (*Slp*, degree), elevation (*Elv*, m) and aspect (*Asp*, degrees, 0-360º) for the study area. A real-time-kinematic GPS (RTK-GPS) was used to mark the locations of water troughs and paddock gates as an operator walked across the farm. The information was used to create a GIS layer of the locations of water troughs and paddock gates for the study area.

Statistical analysis

Urine sensors provided data from 15 cows only, as nine of the urine sensors did not work correctly and data from these were excluded in the overall analysis. Individual urination events were detected using a Visual Basic macro written for Microsoft Excel to filter data and identify when temperature exceeded an arbitrary set threshold (300 mV ≡ ~ 30ºC) (Betteridge *et al.,* 2010b). The mean number of urinations per cow per hour were calculated using MINITAB 15 for Windows (Minitab Inc., State College, Pennsylvania). Differences between means, in relation to temporal and animal factors, were tested by one way analysis of variance (ANOVA), blocked on hour-of-the-day, grazing period and cows' identification number (Minitab Inc., State College, Pennsylvania). Pearson correlation coefficient was used to examine the relationships between the mean number of urinations and animal factors (i.e. age and milking order position).

Urine point density and distribution was investigated using ArcGIS 9 (ArcMap Version 9.3, USA) and R 2.10.1 for Windows (R Development Core Team). 'Intensity' is the average density of points (number of point per unit area) and it is the first step in the analysis of the point pattern (Baddeley, 2008). Kernal Smoothing (KS) is a non-parametric way of estimating the probability density function of a random variable and was used in this case to calculate the urine density distribution. Urination density (U_{den}, per $25m^2$) results are presented in a GIS layer where KS is based on a grid cell of 5m x 5m for each paddock with a bandwidth of 25. Bandwidth was selected visually (Krisp *et al.,* 2009).

The next step in analysing point patterns is to test for complete spatial randomness of points in an area. Complete spatial randomness (CSR) describes a point process whereby point events occur within a given study area in a completely random fashion. Such a process is often modelled using only one parameter, i.e. the density of points (ρ) within the defined area. Under CSR, points are independent of each other and have the same probability of being found at any location. CSR is also called a spatial Poisson process and there are several tests that can be used to analyse this process. The Kolmogorov-Smirnov (K-S) test for CSR (K-S CSR) compares the observed and expected distribution of the values of some function T (Baddeley, 2008) and was used to analyse spatial patterns of urinations.

A transect was positioned through each 5m x 5m grid cell recording urination and GPS point density, slope, elevation, aspect and pasture mass for each cell in every paddock. In addition, the distance of water troughs (W_{dis}) and paddock gates (G_{dis}) to each cell was also calculated. Pearson correlation coefficient was used to examine the relationships between urination and GPS point density, slope, elevation, aspect, pasture cover and the locations of water troughs and paddock gates.

Results

The mean number of daily urinations events for cows was 9.7 events/day (SD 2.12). A total of 1022 urination events were recorded in this study, equating to a mean = 0.41 urinations cow/hour (SD 0.278). There were significant effects amongst individual cows on the frequency of urination per 24 h ($P < 0.0001$), but these differences did not appear to be caused by age ($r = 0.10$) or milking order ($r = 0.05$). The majority of urinations (85% of total) occurred on pasture, 5% along the races and 10% in the holding yard and the milking shed ($P < 0.001$). The time of day had a significant effect on the frequency of urination during PM grazing ($P < 0.001$), but not during AM grazing ($P = 0.5$). Urination activity decreased after 19:00 h and increased again after 04:00 h (Figure 1.).

Urination density and distribution

Kernel density estimation indicated a non-homogeneous intensity of urination events within all paddocks, an example of which is given in Figure 2. Urination density ranged from 0 to 0.057 urinations per 25m^2 during PM grazing and from 0 to 0.048 urination per 25m^2 during AM grazing. A non-random distribution is indicative of aggregation of urine within particular areas of the paddocks. All paddocks were found to have a non-random urine distribution to some extent, however, patterns of urination were found to have significant non-random distribution in only six of the 12 paddocks (Figure 3.).

Relationships between urine density (U_{den}) and environmental factors

There was a highly significant relationship between U_{den} and the time spent in a location (T_{den}) overall, with strong correlations between U_{den} and T_{den} were observed in several individual paddocks (Table 1). In general, U_{den} was not significantly related to *Slope*, but there was a significant negative relationship between U_{den} and *Slope* in four paddocks. U_{den} was negatively related to P_{mass}. However, on a per paddock basis, U_{dens} was found to have a significantly positive correlation with P_{mass} in four paddocks and a negative correlation in only one paddock. U_{den} was significantly, but weakly negatively related to *Elevation*. Only four paddocks showed significant correlations between U_{den} and *Elevation*.

Distance to paddock gates (G_{dis}) was positively correlated with U_{den}, while distance to water troughs (W_{dis}) was found to be negatively related to U_{den} on the whole (Table 2). There was variation in the type of correlation between G_{dis} and U_{den} amongst paddocks. In five of the paddocks G_{dis} was significantly and positively related to U_{den}, while in three of the paddocks G_{dis} was significantly, but negatively related to U_{den}). In contrast, in six paddocks W_{dis} was significantly negatively related to U_{den}, while a positive correlation was found in only one paddock.

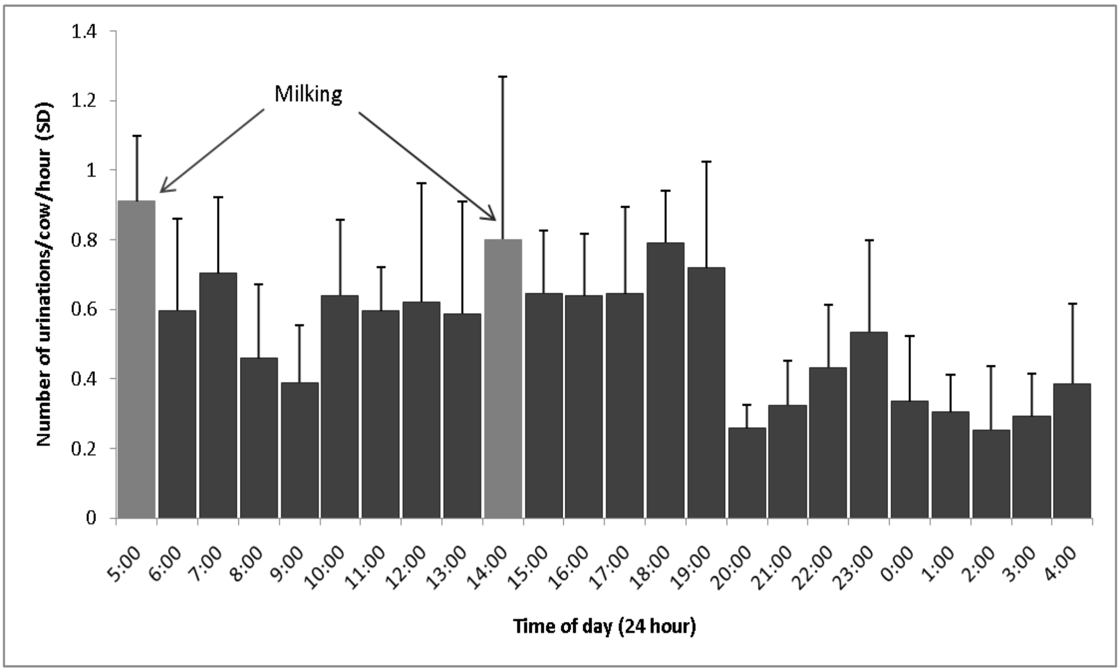

Figure 1. Temporal distribution of urination events of 15 cows over seven consecutive days.

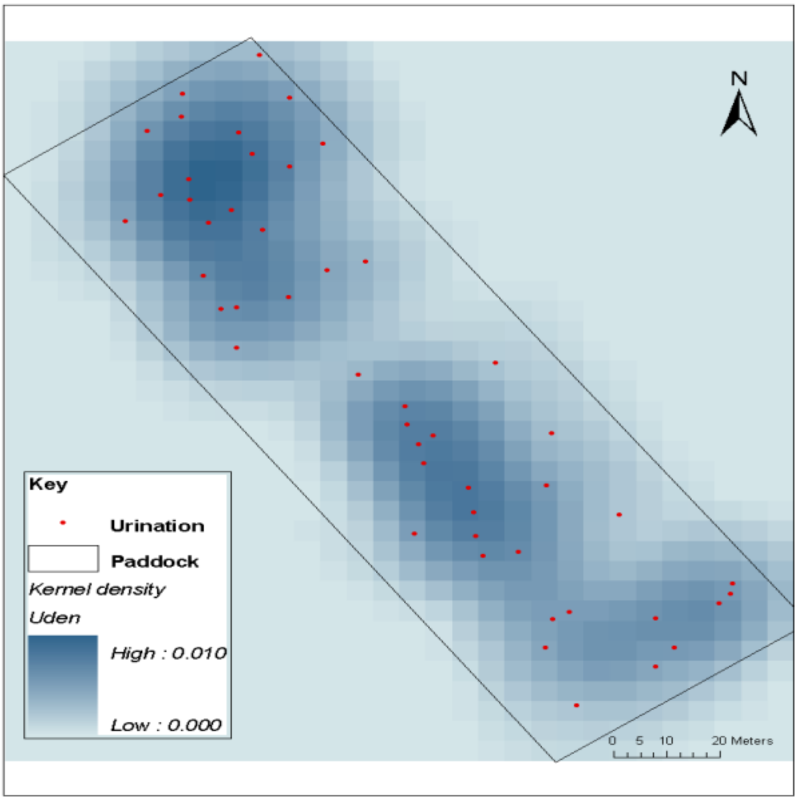

Figure 2. A Kernel density estimate of urination based on a 5m x 5m cell grid in Paddock 6, with actual urine events being superimposed.

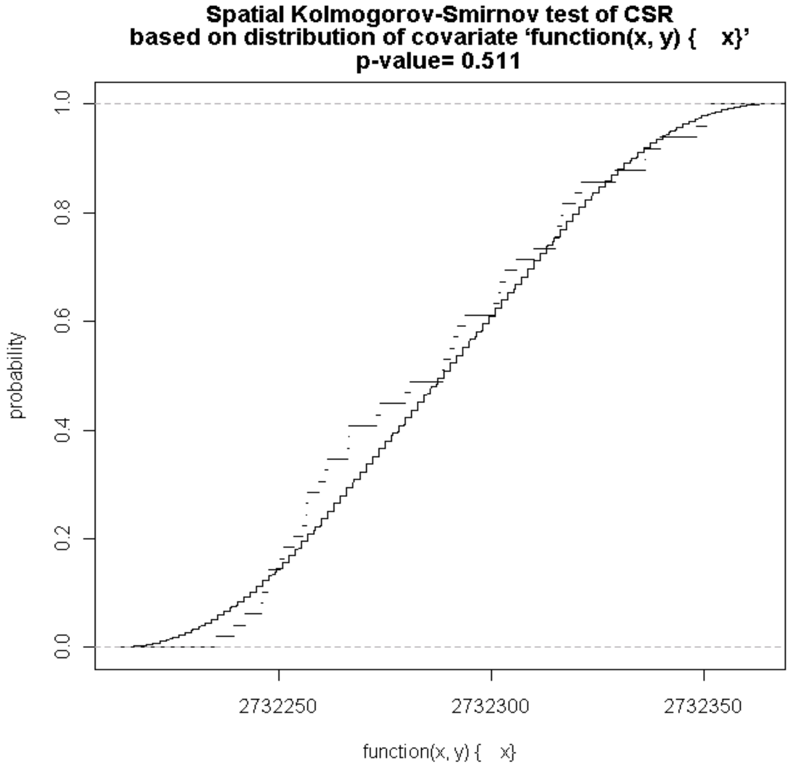

Figure 3. Results from Kolmogorov-Smirnov test for complete spatial Randomness of urinations for Paddock 6. Deviation of the observed distribution from the normal curve (predicted distribution) indicate aggregation of urine within particular areas of the paddock.

Table 1. Correlation coefficients and their significance amongst variables.

	U_{den}	T_{den}	*Slope*	P_{mass}	*Elevation*
T_{den}	0.485				
	***				
Slope	-0.061	-0.074			
	NS	NS			
P_{mass}	-0.191	0.100	0.077		
	***	*	NS		
Elevation	-0.107	-0.080	-0.198	0.048	
	**	*	***	NS	
Aspect	-0.075	-0.029	-0.151	-0.194	0.028
	*	NS	***	***	NS

***: $P < 0.001$; **: $P < 0.01$; *: $P < 0.05$; NS: not significant.
U_{den}: urine point density per 25m^2; T_{den}: GPS point density per 25m^2; P_{mass}: pasture mass (kg DM/ha).

Table 2. Correlation coefficients and their significance amongst variables. U_{den}: density of urination events based on kernel smoothing; T_{den}: density of GPS points based on kernel smoothing; P_{mass}: pasture mass (kg DM/ha).

	U_{den}	T_{den}	G_{dis}
T_{den}	0.485 ***		
G_{dis}	0.132 ***	0.058 NS	
W_{dis}	-0.119 ***	0.011 NS	0.305 ***

***: P < 0.001; **: P < 0.01; *: P< 0.05; NS: not significant.
U_{den}: urine point density per 25m2; T_{den}: GPS point density per 25m^2;
G_{dis}: distance (m) to paddock gates: W_{dis}: distance (m) to water troughs.

Discussion

The mean number of daily urination events (9.7 events/day) was similar to results from the literature. Peterson *et al.* (1956) reported that dairy cows averaged 8 urinations/day. White *et al.* (2001) found that Holsteins dairy cows had a higher mean number of daily urinations than Jerseys (9 events/day and 8.7 events/day respectively). Dairy cows were found to urinate on average 0.41 times/hour over a 24 h period in this study, while Oudshoorn *et al.* (2008) reported that dairy cows urinated on average 0.26 times per hour, however, the results presented were only for urination events recorded when the cows were grazing in the paddock and not over 24 hours.

The herd management system in this study meant that the majority of urinations by cows in this study (85%) were deposited on pasture, which is similar to the finding of White *et al.* (2001) and Clark *et al.* (2010) (84.1% and 90% respectively) with twice daily milking. More urination events were observed during afternoon (PM) grazing and during morning milking times. Cows spent longer in the paddock during PM grazing compared to the time spent on the paddock during morning (AM) grazing, resulting in a greater chance to urinate in the field in the afternoon. The increase in urination frequency during morning milking can be attributed to the need of cows to void themselves following a period of rest and relative inactivity in the time prior to being gathered for morning milking. Time had a significant effect on the frequency of urination during the PM grazing period, but not during the AM grazing. Urination frequencies were high between 15:00 h and 19:00 h, following this period urination frequency decreased and remained low until 05:00 h. The decrease in urination frequency coincided with sunset (19:45 h), similar results were also reported by Betteridge *et al.* (2010a) studying urination behaviour of sheep in a hill country environment.

Urine patch density varied and was not uniform within paddocks. Paddocks used for PM grazing were found to have areas with higher urination density than paddocks used for grazing after morning milking. Areas of higher urine patch density are more likely to have an overlap of urine patches (Pleasants *et al.*, 2007). Thus, some areas within paddocks with high urine densities are likely to receive higher N loads than the average for the paddock.

Urine patch distribution was significantly non-random in six of the 12 paddocks, although visually distinctive distribution patterns were evident within all paddocks. These distribution patterns are indicative of aggregation of urine patches within particular areas of the paddocks and are contradictory to N cycling models that assume homogeneous urine distribution across paddocks (Wheeler *et al.,* 2008; Schoumans *et al.,* 2009).

Time spent in a location was related to the density distribution of urination in this study, which shows that the longer a cow spends in an area the greater the chance of urine being deposited there. Time spent in a location, however, did not show any relation to urination density in four of the paddocks. Although no obvious explanation could be found for these discrepancies, it is possible that other factors play a role in determining urination distribution.

More urinations were detected in areas where the pasture mass was higher in four of the paddocks. On the whole, the results were surprising as it might have been expected that cows would have spent more time in areas with high pasture mass, in order to maximise intake (Saggar *et al.,* 1990), resulting in higher urination densities in these areas.

Elevation was a factor affecting urination density distribution in four of the 12 paddocks, but there was no strong relationship between the two in general. Betteridge *et al.* (2008) reported that elevation is moderately correlated with cow urine distribution and time spent in a location in hill country, with flat areas corresponding to lower elevated areas, attributing the relationship to slope rather than elevation alone. Although flatter areas were found at higher elevations in this study as well, there was very little variation in elevation within paddocks which is likely to have an effect on results.

The aspect of the paddocks varied from Southeast to North facing with no clear relationship between aspect and urination density overall. Aspect was found to have an effect on urination density distribution in six of the paddocks when individual areas were examined. However, as aspect within paddocks varied greatly, it was not possible to determine with certainty whether urine distribution is affected by animals preferring or avoiding areas with specific aspect.

Air temperature, humidity and rainfall were relatively consistent throughout the study with no strong winds or extremes of weather. The effect of elevation and aspect on the distribution of urination density is unclear and it might not be a driving factor in determining urine distribution on this dairy farm or other relatively flat farms. Seasonal studies may provide more information on how elevation and aspect influence urine distribution on dairy farms.

Surprisingly, urine patch density distribution was found to be higher near the paddock gates in only three of the paddocks, with cows never being observed to congregate near the gate prior to being herded away for milking. This is in contrast to some studies (Matthew *et al.,* 1988; McDowell, 2006) which found increased soil fertility caused by more urine and dung patches near gateways and shelter. This is partly thought to be a management effect, for example, if forage has been depleted, dairy cows would be more likely to gather near gateways and wait to be taken in for milking.

Conclusions

1. Urine sensors and GPS units proved to be an effective method for capturing data on the temporal and spatial urination behaviour of a dairy cow herd.
2. Urine deposition was non-random indicating that there was an aggregation of urine patches within grazed paddocks.
3. The spatial density patterns of urine patches indicate that there is an association between urination and the time spent in a location. While the physical properties of the paddocks did not have an effect on the density of urination behaviour in this study.

The time spent in a location was the main factor influencing urine patch density and therefore distribution patterns in this study. However, factors such as topography and pasture mass can all affect urine distribution through the effect of these on other behaviour patterns.

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