THE USE OF SENSING TECHNOLOGIES TO MONITOR AND TRACK THE BEHAVIOUR OF COWS ON A COMMERCIAL DAIRY FARM

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ABSTRACT

New Zealand farmers are facing rapidly increasing pressure to reduce nutrient losses from their farming enterprises to the environment caused by grazing ruminants. Research suggests that the major source of nutrient loss is animal excreta, which for N relates to cattle urine in particular. Most models used to describe N cycling and predict loss assume homogeneous distribution of urine patches across grazing areas. This study aims to provide base line knowledge of how dairy cows distribute urine, by using sensor technologies to investigate the patterns of excreta distribution in dairy cows under commercial conditions. The study took place on a commercial dairy farm, No 4 Dairy Farm, Massey University, Palmerston North, New Zealand during early autumn in March 2009. Thirty cows in late lactation, balanced for milking order and age, from a herd of 180 milking cows, were fitted with global positioning system (GPS) collars, and urine sensors for seven consecutive days. The herd was milked twice a day and rotationally grazed, without supplementation. 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. Kernel density estimates indicated that urine patch distribution was inhomogeneous, thus there was aggregation of urine patches within particular areas of the paddocks. Moderate correlations between the time spent in a location and urine patch density provided evidence that the time spent in a particular location was a factor affecting the density of urine patches. Substantial variation in results between paddocks suggested that paddock characteristics did not play a major role in determining urine distribution patterns in this study. It is concluded that a suitable methodology was developed to observe and track the behaviour of dairy cows managed on pasture under commercial conditions using precision and sensor technologies.

Keywords: precision agriculture, dairy cows, urination, GPS, urine sensors.

INTRODUCTION

Research suggests that the major source of nutrient loss to the environment 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 (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).

Most studies that describe urination behaviour of grazing dairy cows are conducted as a comparison between treatments under an experimental design and not under typical commercial conditions (Peterson *et al.*, 1956; White *et. al.*, 2001; Oudshoorn *et. al.*, 2008; Clark *et al.*, 2010). These studies are conducted to investigate particular factors and so only specific aspects of urine distribution related to these factors are studied. Therefore, such studies provide only a limited amount of information about urination behaviour of grazing dairy cows under commercial grazing management. Emerging GPS tracking technologies are now sufficiently robust that they could be used to monitor animals in a large commercial dairy herd. The use of GPS tracking and urine sensors allow a more precise study of animal behaviour and the spatial distribution of urine by livestock. A better understanding of urine transfer by livestock will give an improved indication of N losses, where these occur, and how these might impact the environment, N-leaching models and create a potential for new management solutions.

This study aimed to identify and test continuous methods of accurately tracking individual dairy cows within a herd, and to provide base-line knowledge of how dairy cows (*Bos taurus*) distribute urine on a commercial dairy farm.

MATERIALS AND METHODS

The study took place on a commercial dairy farm 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 supplementary feeds were offered throughout the study. Weather data for the duration of the study were obtained from the weather station based at the farm. The average times of sunrise and sunset were 07:15 h and 19:45 h, respectively.

The dairy herd comprised 180 cross-bred cows in late lactation (210 days ± 30 days) with average herd production of 6.8 l/day and an average herd body condition score of 3.7 on a 1 to 5 scale (DairyNZ, 2004). Cows were milked twice a day in a rotary dairy parlour. The milking process involved the entire herd being removed from pasture by a person on a four-wheel motorbike and being herded along the farm tracks to the milking shed. The herd was assembled in an uncovered concrete holding yard (with backing gate) adjacent to the dairy and milking commenced once the whole herd had been confined in the yard. Once an individual cow had been milked it was immediately free to make its own way back along the farm tracks to a designated paddock. Cows received a fresh allocation of approximately 1.2 ha (SD 0.13) of pasture after each milking. 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).

Animal Measurements

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. All animal experimentation was carried out following approval by the Massey University Animal Ethics Committee (Protocols 08/06 and 08/53).

Thirty cows that were selected for the study were fitted with GPS units which were custom-made using Trimble® Lassen GPS modules programmed to allow for continual tracking of satellites and logging of animal positions whenever a cow moved ≥4 m or every 1 min if the cow did not move during that time. The GPS units were powered by one 3.6-V, 19-Ah Tadiran™ battery with a life under continuous GPS use of 8 – 10 days. The GPS unit was enclosed in a plastic box and attached to an adjustable leather collar. A Trimble® Active antenna was also attached to the leather collar and placed around the neck of the cow in such a position that the antenna was situated at the nape of the neck and the GPS unit under the animal's neck.

The GPS units were programmed to run continuously rather than have duty cycle intervals for two main reasons: 1) GPS units provided spatial reference for other sensors which recorded data continuously, but did not have GPS capability. This avoided the possible loss of data from other sensors; and 2) studies (Mills *et al.*, 2006; Swain *et al.*, 2008) have demonstrated that an increase in GPS fix rate, with the decrease of grazing area, improve the accuracy of predicting animal location.

The GPS unit recorded date and time (GMT), latitude, longitude, HDOP (horizontal dilution of precision) and the number of satellites used to achieve a location measurement. The GPS coordinates were converted to New Zealand Map

Grid coordinates using GIS software and a GIS layer of GPS locations was generated.

Twenty four of the thirty 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 a 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 output was used to create GIS layers of pasture mass (P_{mass}, kg DM/ha) for each paddock in the study. Only data for eight of the 12 paddocks were used for analysis. The GIS layer was generated using 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. 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). 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). Kernel smoothing (KS) was used to estimate urine patch density (Baddeley, 2008). Kernel smoothing establishes the probability density function of a random variable. If x_1, x_2, ..., $x_n \sim f$ is an independent and identically-distributed sample of a random variable, then the kernel density approximation of its probability density function is:

$$\hat{f}_h\ (x) = \frac{1}{nh}\sum_{i=1}^{n} K\ \left(\frac{x - x_i}{h}\right)$$

where K is kernel and h is a smoothing parameter called the bandwidth. Typically K is taken to be a standard Gaussian function with a mean of zero and a variance of 1. Thus, the variance is controlled indirectly through the parameter h:

$$K\left(\frac{x - x_i}{h}\right) = \frac{1}{\sqrt{2\pi}} e^{-\frac{(x-x_{i)}}{2h^2}}$$

Urination density (U_{den}, per 25m^2) results are presented in a GIS layer where KS is based on a grid cell of 5m × 5m for each paddock with a bandwidth of 25. Bandwidth was selected visually (Krisp *et al.*, 2009).

GPS point data were used to investigate the spatial preference of animals for locations within each paddock. GPS 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, New Zealand). Similar to the techniques used to analyse urine point density, kernel smoothing was used to investigate GPS point density and spatial distribution. GPS point density (T_{den}, per 25m^2) results are presented in a GIS layer where KS is based on a grid cell of 5m × 5m for each paddock with a bandwidth of 25. Bandwidth was selected visually (Krisp *et al.*, 2009).

A transect was positioned through each 5m × 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 ($P < 0.001$). Significantly more urination events were recorded during the PM grazing periods

(55.5% in 14 h) compared with the AM grazing periods (44.5% in 8 h) out of the total urination events on pasture ($P < 0.05$). More urination events occurred in the races, in the holding yard and the milking shed in the morning than in the afternoon (53% and 47%, respectively) ($P < 0.01$).

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). During PM grazing 56% of urinations were deposited between 15:00 and 20:00 h with the rest (44%) placed in the paddock between 20:00 and 04:00 h. These urination patterns were consistent within each of the paddocks whether in AM or PM grazing periods, with no significant differences in urination frequencies between paddocks (AM, $P = 0.2$; PM, $P = 0.5$).

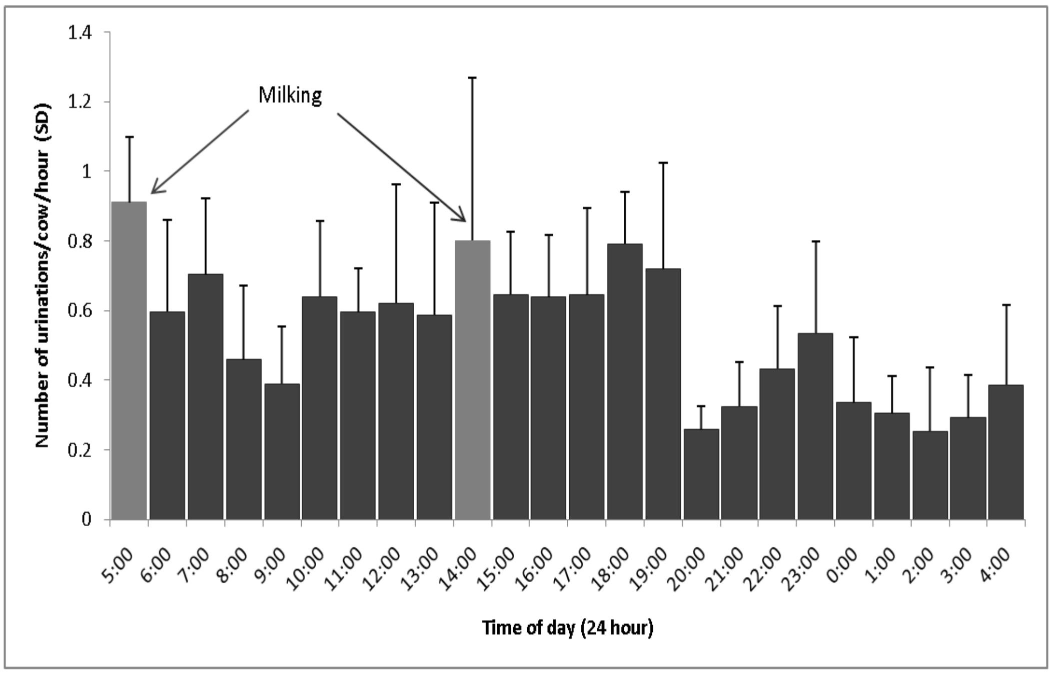

Figure 1. Temporal distribution of urination events of 15 cows over seven consecutive days. (From Draganova 2012)

Kernel density estimation indicated a non-homogeneous intensity of urination events within all paddocks. 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.

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.

Table 1. Correlation coefficients and their significance amongst variables. (From Draganova 2012).

	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). (From Draganova 2012).

	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 previous reports of dairy cow urination frequencies. 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. Similar to the result in this study, Clark *et al.* (2010) reported that cows urinated on average 0.60 times/hour. Data showed significant variations in the frequencies of daily urination patterns between animals, similar to results presented by Aland *et al.* (2002) for dairy cows kept indoors. It is unclear as to what might have caused these differences in this and other studies. However, Betteridge *et al.* (1986) showed that the variation in the frequency of urination between steers was influenced by temperature.

The herd management system in this study meant that (85%) of urinations by cows 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. It should be noted however, that Clark *et al.* (2010) have included urination deposited on races in the overall field urination events. That study also reported that 10% of all urinations were deposited at a standoff pad and dairy, similar to findings in this study (10% of urination deposited at the holding yard and dairy). In contrast, White *et al.* (2001) did not observe urination events on the races, but reported that 12.3% of urination events were deposited at the feeding area with the remaining 3.6% at the holding yard and dairy. In this study 5% of urinations occurred while cows were in raceways proceeding to and from milking. These differences are most likely due to cow numbers and how cows were managed in the latter study. The herd used by White *et al.* (2001) was very small (n = 36) and the cows spent a relatively short time walking, waiting to be and being milked, which reduces the opportunity available to urinate in these areas. On the other hand, those animals were fed prior to being milked, spending time at the feeding area and thus being provided with a chance to urinate there. It is evident that results from the current study are similar to results presented in the literature, providing indirect evidence that the present method used to gather data on urination behaviour of commercially managed dairy cows is reliable.

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. For example, concentrations of excreted N in urine patches can be equivalent of up to 1000 kg N per hectare (Haynes and Williams, 1993), with excreta deposits covering 10% of the paddock area for dairy cows (White *et al.*, 2001) and 14% of the paddock area for set-stock cattle (Betteridge *et al.*, 2010a). Often less than 60% of nutrients deposited in urine patches per year are taken up by the pasture and recycled back to pasture when grass is consumed by grazing animals (Haynes and Williams, 1993). When urine patches overlap, N concentration increases (Pleasants *et al.*, 2007) and the percentage of N recycled by pasture growth reduces and N leaching under winter drainage would increase (White *et al.*, 2001; McGechan and Topp, 2004).

A non-uniform density of urine patches within paddocks is indicative of aggregation of urine patches within particular areas of the paddocks and is contradictory to N cycling models that assume homogeneous urine distribution across paddocks (Wheeler *et al.*, 2008; Schoumans *et al.*, 2009). Several factors can have an effect on patterns of urine distribution in space and time. Factors such as time spent in a location (White *et al.*, 2001; Betteridge *et al.*, 2008), slope (Moir *et al.*, 2005; Betteridge *et al.*, 2010a), gateways (McDowell, 2006), water troughs (White *et al.*, 2001; McDowell, 2006) and stock camps (Betteridge *et al.*, 2007, 2010a) can all have an influence on urine patch distribution patterns.

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. Even though some paddocks had relatively steep areas (>25º), slope did not appear to have a significant role in determining urine patch distribution in this study. Slope did have some effect on urine patch density distribution in four of the paddocks. These results are somewhat misleading however, as these paddocks were mostly flat with a small area having steep slopes. The paddocks allowed the cows to forage and find places to rest without the need to spent time in the steep areas of the paddocks, thus skewing results. Moir *et al.* (2005) reported a higher urine patch density on low (0-3º) than on higher slope (7-15º) areas for dairy cows on pasture. Other studies, carried out with beef cattle, have also found that urine patches are more likely to occur on relatively flat areas in steep hill country (Betteridge *et al.*, 2010a). One reason for differences here may be explained by the physical characteristics of the paddocks in this study. As stated before, most paddocks had large relatively flat areas which provided sufficient area for foraging and resting without the need to explore the steeper areas. In contrast to set-stock management, dairy cows are in a paddock for a relatively short duration and have less opportunity or need to spend time on steep slope areas compared to sheep or beef cattle grazing in the same paddock for longer periods.

More urinations were detected in areas where the pasture mass was higher in four of the paddocks. On the whole, these 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.*, 1990b), resulting in higher urination densities in these areas. Likewise, Betteridge *et al.* (2008) did not find that pasture mass influenced urination distribution of sheep, but their paddock had an unusually high pasture mass for sheep. Similarly, pasture in this study had a mean pre grazing mass of 3535 kg DM/ha (mean post grazing pasture mass estimated at 1200 kg DM/ha by farm staff) giving an allocation of 13 kg DM/ha per cow per grazing, more than what is typically allocated to dairy cows at this stage of lactation (Dairy NZ, 2010). Therefore, with sufficient forage available in relation to requirements, cows are less likely to spend time searching for areas with high pasture mass and thus are less likely to spend time in these areas and have the opportunity to deposit urine.

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. East to Southeast areas tended to also be areas where slopes were steeper, while West to North areas had less slope. A similar relationship was recorded between pasture mass and aspect.

Air temperature, humidity and rainfall were relatively consistent throughout the study with no strong winds or extremes of weather. Prevailing winds or strong sun radiation may have an effect on animal behaviour (Hemsworth *et al.*, 1995). For example, animals may choose to spent time in areas with a specific aspect or elevation in order to find shelter from strong winds or to maximise sun exposure during cold temperatures, with the relevance of these factors changing with season. 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. Although the studies do not explain the exact reason causing the increase in urination density near gateways, animals can congregate near gates for variety of reasons. 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. If the herd is moved from pasture only when all the animals are gathered near the gate by the herd manager, there will be a greater opportunity for cows to urinate near the gate while they wait for all the animals to come together. Cows in this study had adequate pasture allocation and forage was not completely depleted during any grazing period. Furthermore, gates were left open prior to moving the animals off pasture, resulting in a steady stream of individuals through the gates. This might explain why there was no clear relationship between urination density distribution and gateways in general, but it does not provide an explanation as to why relationships between the two were found in the three individual paddocks.

Areas with higher urination densities were observed closer to water troughs in six of the paddocks. Urine density increased with distance from the water source in only one paddock. Higher than average deposits of urine around the water trough were reported by White *et al*. (2001) with concentrations of excreta within 30 meters of the water trough being significantly greater in the warm months of the year than concentrations in the cooler seasons. Results in that trial were only significant when the average air temperature exceeded 22ºC, a level which has been considered to trigger heat stress in dairy cows (Dougherty *et al.,* 1991; Armstrong, 1995). Heat stress is unlikely to be the primary cause generating higher urination density near water troughs in this study as the average air temperature ranged from 10.2 to 17.6ºC. Although air temperature did reach 22.2ºC during the study, it was of a relatively short duration (less than 1 h) and it is dubious whether it could have caused the urination density patterns to change.

CONCLUSIONS

Urine sensors and GPS units proved to be an effective method for capturing data on the temporal and spatial urination behaviour of individuals within a dairy cow herd. Urine deposition was non-random indicating that there was an aggregation of urine patches within grazed paddocks. The spatial density 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 results gained from the technology used in this trial appear to be consistent with smaller trials which were manually observed. The technology was further validated against manual observation and appeared to gather reliable results but it was also capable of continuously monitoring much larger groups of animals for longer periods of time in an unbiased way. This has been difficult to achieve using observation over a longer time period. These methods would also allow continuous trials which could identify further urine deposition in repeated grazing events throughout the whole year in order to build a more complete picture and better understand of the impact of management practices and environmental factors.

REFERENCES

Aland, A., Lidfors, L. and Ekesbo, I., (2002). Diurnal distribution of dairy cow defecation and urination. *Applied Animal Behaviour Science 78*, 43-54.

Armstrong, D.V. (1995). Heat stress interaction with shade and cooling. *Journal of Dairy Science 77*, 2044-2050.

Baddeley, A. (2008). *Analysing spatial point patterns in R.* Rockhamption, Qld, Australia: CSIRO.

Betteridge, K., Costall D., Balladur, S., Upsdell, M. and Umemura, K. (2010a). Urine distribution and grazing behaviour of female sheep and cattle grazing a steep New Zealand hill pasture. *Animal Production Science 50*, 624-629.

Betteridge, K., Hoogendoorn, C., Costall D., Carter, M., Griffiths, W. (2010b) Sensors for detecting and logging spatial distribution of urine from grazing female cattle and sheep. *Computers and Electronics in Agriculture 73*, 66-73.

Betteridge K, Kawamura, K., Costall, D., Carter, M., Hoogendoorn, C, Griffiths W and Inoue, Y. (2008). Tools to determine impact of animal behaviour on nitrogen leaching and nitrous oxide emissions. In, *Proceedings of the Annual Fertiliser and Lime Research Centre Workshop*. Massey University, New Zealand.

Betteridge, K., Costall, D., Hoogendoor, C., Carter, M. and Griffiths, W. (2007). GPS and urine sensor for sheep and cattle to improve nitrogen models and identify sources areas for targeted mitigation management. In, *Proceedings of the 11th Annual Australasian Symposium on Precision Agriculture* (p. 29). Lincoln University, New Zealand.

Betteridge, K., Andrewes, W.G.K., Sedcole, J.R.K. (1986). Intake and excretion of nitrogen, potassium and phosphorus by grazing steers. *Journal of Agricultural Science 106*, 393-404.

Clark, C.E.F., McLeod, K.L.M., Glassey, C.B., Gregorini, P., Costall, D.A., Betteridge, K. and Jago, J.G. (2010). Strategically reducing time on pasture: Dairy cow intake, production, welfare and excretory behaviour. *Journal of Dairy Science 93*(5), 2280-2286.

Dairy NZ (2008). New Zealand Dairy Statistics.

Di, H.J. and Cameron, K.C., (2002). Nitrate leaching in temperate agroecosystems: sources, factors and mitigating strategies. *Nutrient Cycling in Agroecosystems 64*, 237-256.

Dougherty, C.T., Lauriault, L.W., Bradley, N.W., Gay, N. and Cornelius, P.L. (1991). Induction of tall fescue toxicosis in heat-stressed cattle and its alleviation with thiamine. *Journal of Animal Science 69*, 1008-1018.

Draganova, I.G. (2012) Nutrient Redistribution and Behaviour of Livestock in an Intensively Managed Dairy System. Unpublished PhD diss. Palmerston North, New Zealand, Massey University.

Franzluebbers, A.J., Stueddemann, J.A. and Schomberg, H.H. (2000). Spatial distribution of soil carbon and nitrogen pools under grazed tall fescue. *Soil Science Society Journal 64*, 635-639.

Haining, R. (2003). *Spatial data analysis*. UK: Cambridge University Press.

Haynes, R.J. and Williams, P.H. (1993). Nutrient cycling and soil fertility in the grazed pasture ecosystem. *Advances in Agronomy 49*, 119-199.

Hemsworth, P.H., Barnett, J.L., Beveridge, L. and Matthews, L.R (1995). The welfare of extensively managed dairy cattle: a review. *Applied Animal Behaviour Science 42*, 161-182.

Krisp, J.M., Peters, S., Murphy, C.E. and Fan, H. (2009). Visual bandwidth selection for kernel density maps. *Journal of Geoinformation 5*, 445-454.

Ledgard, S.F., (2001). Nitrogen cycling in low input legume-based agriculture, with emphasis on legume/grass pasture. *Plant and Soil 228*, 43-59.

Matthew, C., Tillman, R.W., Hedley, M.J. and Thompson, M. (1988). Observations on the relationship between soil fertility, pasture botanical composition and pasture growth rate; for a North Island Lowland Pasture. *Proceedings of the New Zealand Grasslands Association 49*, 141-145.

McDowell, R.W., (2006). Phosphorus and sediment loss in a catchment with winter forage grazing off cropland by dairy cattle. *Journal of Environmental Quality 35*(2), 575-583.

McGechan, M.B. and Topp, C..F.E., (2004). Modelling environmental impact of deposition of excreted nitrogen by grazing dairy cows. *Agriculture, Ecosystems and Environment 103*, 149-164.

Mills, K.J., Patterson, B.R. and Murray, D.L. (2006). Effects of variable sampling frequencies on GPS transmitter efficiency and estimated wolf home range size and movement distance. *Wildlife Society Bulletin 34*(5), 1463-1469.

Moir, J.L., Fertsak, U., Cameron, K.C. and Di, H.J. (2005). The spatial distribution and area coverage of urine depositions in grazed dairy or sheep and beef pastures in New Zealand. In, *The 18^th^ World Congress of Soil Science*, Philadelphia, Pennsylvania, USA.

Monaghan, R.M., Hedley, M.J., Di, H.J., McDowell, R.W., Cameron, K.C. and Ledgard, S.F., (2007). Nutrient management in New Zealand pastures – recent developments and future issues. *New Zealand Journal of Agricultural Research 50*,181-201.

Oudshoorn, F. W., T. Kristensen and E. S. Nadimi (2008). "Dairy cow defecation and urination frequency and spatial distribution in relation to time-limited grazing." *Livestock Science 113*(1), 62-73.

Petersen, R.G., Lucas, H.L. and Woodhouse, W.W., (1956). The distribution of excreta by freely grazing cattle and its effect on pasture fertility: 1. Excretal distribution. *Agronomy Journal 48*, 440-444.

Pleasants, A.B., P.R. Shorten and G.C. Wake (2007). The distribution of urine deposited on a pasture from grazing animals. *Journal of Agricultural Science 145*(1), 81-86.

Saggar, S., Mackay, A.D., Hedley, M.J., Lambert, M.G. and Clark, D.A. (1990). A nutrient transfer model to explain the fate of phosphorus and sulphur in a grazed hill country pasture. *Agric. Ecosystems Environ. 30*, 295-315.

Schoumans, O.F., Silgram, M., Walvoott, D.J.J., Groenendijk, P., Bouraoui, F., Andersen, H.E., Lo Porto, A., Reisser, H., Le Gall, G., Anthony, S., Aeheimer, B., Johnsson, H., Panagopoulos, Y., Mimikou, M., Zweynert, U., Behrendt, H. and Barr, A. (2009). Evaluation of the directness of eight model applications to assess diffuse annual nutrient losses from agricultural land. *Journal of Environmental Monitoring 11*, 540-553.

Shorten, P. R. and A. B. Pleasants (2007). A stochastic model of urinary nitrogen and water flow in grassland soil in New Zealand. *Agriculture, Ecosystems & Environment 120*(2-4), 145-152.

Stuth, J.W., (1991). Foraging behaviour. In, Heitschmidt, R.K. and Stuth, J.W. (Eds.) *Grazing Management: An Ecological Perspective*. Portland, OR, USA: Timber Press.

Swain, D.L., Wark, T. and Bishop-Hurley, G.J. (2008). Using high fix rate GPS data to determine the relationships between fix rate, prediction error and patch selection. *Ecological Modelling 212*, 273-279.

Wheeler, D.M., Ledgard, S.F. and DeKlein, C.A.M. (2008). Using the OVERSEER nutrient budget model to estimate on-farm greenhouse gas emissions. *Australian Journal of Experimental Agriculture 48*, 99-103.

White, S.L., Sheffield, R.E., Washburn, S.P., King, L.D. and Green, J.T. Jr., (2001). Spatial and time distribution of dairy cattle excreta in an intensive pasture system. *Journal of Environmental Quality 30*, 2180-2187.