Nutrient Distribution and Behaviour of Livestock in an Intensively Managed Dairy System

A thesis presented in partial fulfilment of the requirements for the degree of

Doctor of Philosophy

in

Earth Science

at Massey University, Manawatu,

New Zealand.

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2012

Abstract

New Zealand farmers are facing pressure to reduce nutrient losses from their farming enterprises to the environment. Research suggests that on farms the major source of nutrient loss is animal excreta, which for nitrogen (N) relates to cattle urine in particular. Most models used to predict N cycling and loss assume homogeneous distribution of bovine urine patches across paddocks. This study aims to provide baseline understanding of how dairy cows distribute urine, in regard to activity patterns and several environmental factors, by using sensor technologies to investigate the patterns of excreta distribution from 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 (March) 2009. Thirty cows in late lactation, balanced for milking order and age, 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 each of about ~1.1 ha.

The use of urine sensors, GPS units and IceTag3D®s was an effective method for capturing data on the temporal and spatial behaviour of dairy cows in a commercial herd. The majority of urine (85% of total) was deposited on pasture. Urine deposits, together with grazing, lying, standing and walking behaviour, showed non-homogenous density patterns not conforming to a uniform Poisson distribution, indicating a non-random distribution, implying that there was an aggregation of urine patches and particular behaviours within grazed paddocks. The dairy cows were observed to have distinctive time budgets where the times of sunset and sunrise, together with the removal of cows for milking, were the main factors influencing activity patterns of animals in this study. There were associations between the spatial density patterns of behaviour and urine patches, with time of day influencing the levels of association. Fitting urine patch data with a distribution that is a function of the density of a particular behaviour variable was possible, although patterns were inconsistent. Time of day had a significant effect on the fit of an inhomogeneous Poisson process model with behaviour variables being better predictors of urine patch distribution during night hours than during day-light hours.

In conclusion a suitable methodology was developed to observe, track and analyse the behaviour of dairy cows managed on pasture under commercial conditions using GPS and sensor technologies. Dairy cows were found to deposit the majority of their urine on pasture, where urine patches were found to have a non-random distribution. Understanding of the spatial location and distribution of urine can allow for the development of management practices that target critical source areas of N leaching.

Publications

The following is a list of publications arising from this thesis:

Draganova, I., Yule, I. and Stevenson, M. (2012). The role of cows in redistributing N around the farm. In, *The Proceedings of the 25th Annual FLRC Workshop*. Massey University, New Zealand.

Draganova, I., Betteridge, K. and Yule, I. (2010). Where do cows urinate: tools to aid nitrogen emission mitigation? In, *The Proceedings of the 4th Australasian Dairy Science Symposium*. Lincoln University, New Zealand.

Draganova, I., Yule, I., Betteridge, K., (2010). Monitoring dairy cow activity with GPS-tracking and supporting technologies. In, *The Proceeding of the 10th International Conference on Precision Agriculture*. Denver, USA.

Draganova, I., Yule, I., Betteridge, K., Hedley, M., Stevenson, M. and Stafford, K. (2010). Activity patterns and nutrient redistribution in an intensively managed dairy herd. In, *The Proceeding of the 23rd Annual FLRC Workshop*. Massey University, New Zealand.

Draganova, I., Yule, I., Betteridge, K., Hedley, M., Stafford, K. (2009). Pasture utilisation and nutrient redistribution in intensively managed dairy systems. In, *The Proceedings of the 13th Symposium on the Precision Agriculture*. University of New England, Australia.

Acknowledgments

Firstly, I would like to thank my supervisors Professor Ian Yule, Keith Betteridge, Professor Mike Hedley and Professor Kevin Stafford for their guidance, support and assistance. I am extremely grateful for their ready-support and advice, intellectual input and contribution to my academic development throughout my candidature. This study was made possible with funding provided by the Fertiliser Manufacturers Research Association, thank you.

I would also like to thank the support staff at the Institute of Natural Resources for their help with field work. Special thanks to Matthew Irwin for his technical support, ideas and discussions, to Elizabeth Longley, Sophie Balladur and Des Costall for their help with fieldwork, data entry and arrangement, and to Keith Betteridge for taking on the early morning duties and helping search for lost equipment.

I would like to acknowledge the statistical advice provided by Dr Mark Stevenson, particularly his help with writing code in R, his encouragement and tolerance, and numerous discussions on statistical methods.

All the research in this thesis was conducted on Massey University No.4 Dairy farm. Without the cooperation and assistance of the farm staff this study would not have been possible. I would especially like to thank Conrad for his patience and help drafting cows. All animal experimentation was carried out following approval by the Massey University Animal Ethics Committee (Protocols 08/06 and 08/53).

Finally, I would like to thank my friends and family, for believing in me, for their encouragement and help with childcare. Thanks to my husband and children for their continuous love, support and understanding during some stressful times.

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Chapter One: Review of the Literature

1.1. Introduction

New Zealand farmers are facing pressure to reduce nutrient losses from their pastoral enterprises to the environment. Research suggests that the major pathway for nutrient loss is via 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 nutrient cycling models assume a random distribution of excreta across the paddock (Wheeler *et al.,* 2008; Schoumans *et al.,* 2009). However, non-uniform distribution resulting from stock grazing and camping behaviour is well known and can be caused by contour, water sources, shade and shelter (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; Saggar *et al*., 1990 a and b; McDowell, 2006). It is also probable that areas of the paddock with greater pasture mass and/or higher pasture quality may encourage livestock to spend more time in these areas than elsewhere, with the probability that nutrient distribution may be similarly biased.

Research has shown how animal grazing and camping behaviour resulted in soil at campsites, in tracks (Saggar *et al.,* 1990 a and b) and adjacent to shelter (Matthew *et al.*, 1988), having high nutrient loads. Some farmers maintain that they have a general idea of how this operates, but they do not know the extent to which stock transfer of nutrients affects the soil nutrient concentration within the unique topography and shelter belt systems on their farms. Consequently, fertilisers are typically applied uniformly across the paddock and lead to over-fertilisation in areas already rich in excreta return.

Studies on a sheep (*Ovis aries*) and beef cattle (*Bos taurus*) farm indicated that soil nutrient concentrations were higher in areas where livestock congregated, such as in stock camps (Betteridge *et al.,* 2007). The negative environmental impact due to animal excreta being concentrated in stock camps can be of concern where camps are close to streams and wetlands, or connected through areas of potential channelised flow (McDowell and

Srinivasan, 2009). Losses of N from stock camps will be higher due to the greater probability of overlapping urine patches and consequent exponential rise in the rate of N leaching (Pleasants *et al.,* 2007; Shorten and Pleasants, 2007) and ammonia (NH_3) volatilisation (Di and Cameron, 2002 and 2007).

Topography, pasture mass and quality, available shade and/or shelter can affect the behaviour of individual animals or groups and thus influence nutrient distribution. A paddock having a wide range of these characteristics will be utilised in a variety of ways by livestock (Bailey and WallisDeVries, 1998). For example, flat or low gradient areas might be preferred grazing sites while shaded or sheltered places are favoured for rumination and rest. Livestock are likely to respond to these characteristics in different ways during the different seasons.

Increased intensification of agriculture generally requires higher fertiliser inputs which in turn increases the risk of nutrient loss to the environment. Precision fertiliser application is now being used by some New Zealand farmers. The intention is to apply nutrients differentially across or within paddocks such that wastage through excess rates of applied fertiliser is minimised. Variable rate application of fertiliser within paddocks requires intensive within paddock soil testing and estimation of production potential – data that are costly and difficult to achieve. No account is taken of nutrient input from the animals. New techniques of mapping pasture quantity and quality allied to techniques developed by Lawrence and Yule (2008) to map actual fertiliser application make it possible to work towards a situation where excessive application of nutrients can be avoided. This not only assists in reducing the environmental impact of farming but improves the economic utilisation of fertilisers.

The literature suggests that there is variability in urine patch distribution, but little is known about the spatial variability in urination amongst dairy cows (*Bos taurus*), especially in regard to field topography, paddock characteristics (e.g. water sources, shelter), pasture mass and weather conditions. Such knowledge will help farmers develop more accurate nutrient budgets and plan more spatially precise fertiliser applications. Understanding of urine patch distribution could also be used to improve target application of nitrification inhibitors to N-leaching hotspots (critical source areas - CSAs) within a paddock as opposed to broadcast application across the whole paddock.

1.2. Distribution of excreta

Animal excreta contain a range of nutrients which are valuable assets if they can be utilised by growing plants. However, nutrient content and deposition rates in urine and faeces are in excess of pasture plant requirements and this excess can contribute to environmental pollution by leaching into waterways through seasonal nitrification (McGechan and Topp, 2004). Studies indicate that the amount of N excreted by animals (particularly N from urine) is the most important factor in N-leaching rather than N losses related to inefficiencies in N fertiliser usage (Monaghan *et al.*, 2007). 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 paddock area at any one grazing (White *et al.*, 2001). Some of these nutrients are taken up by the pasture grass and recycled back to pasture when grass is consumed by grazing animals. However, when urine patches overlap, N concentration increases (Pleasants *et al.*, 2007) and N in excess to plant requirements is nitrified to nitrate, which is easily leached in the following drainage season (Houlbrooke *et al.*, 2004) to ground and surface waters (White *et al.*, 2001; McGechan and Topp, 2004).

High levels of N pollution can be attributed to several factors, including localised high stocking rates due to cows congregating in specific areas within a paddock. These localised 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 critical source areas during each drainage season (Houlbrooke *et al.*, 2004; McGechan and Topp, 2004).

Several factors affect patterns of livestock distribution in space and time and consequent dispersal of excreta. Environmental and animal factors such as seasons (White *et al.*, 2001), time spent on pasture (Oudshoorn *et al.*, 2008; Clark *et al.*, 2010), gateways (McDowell, 2006), water troughs (White *et al.*, 2001; McDowell, 2006) and stock camps (Betteridge *et al.*, 2007) can all have an influence on animal distribution and excreta re-distribution patterns.

1.2.1. Factors affecting excreta distribution

Overall Stocking Rate and Localized Density

McGechan and Topp (2004) modelled levels of N-leaching that increased with overall field stocking density, reaching 731.4 kg of N per hectare when the field stocking density was 16 cows/ha. The amount of modelled N leached was also related to time of year, with highest levels of N loss during August to October in New Zealand. This coincides with the onset of low evaporation rates, which lead to soil water recharge, zero soil water deficit and subsequent rainfall causing drainage and runoff events (Houlbrooke *et al.*, 2004). Houlbrooke *et al*. (2004) found the largest N loss was at the beginning of the drainage season (May-June) each year when drainage nitrate concentrations were at their highest.

Stockdale and King (1983) studied the faecal output of grazing dairy cows over a three-day period in mid-summer in Northern Victoria (Australia). They found that the daily number of faecal pads deposited per cow declined by 0.66 for each unit increase in stocking rate. The fresh weight of dung also declined as stocking rates increased by 0.16 kg per unit of stocking rate. At the same time, grazing time decreased as herbage allowance fell below 32 kg of dry matter (DM) cow^{-1} d^{-1}.

Higher than average deposits of excreta around the water trough was reported by White *et al.* (2001) and it was concluded that this was mainly due to warm weather causing increased drinking frequency. Concentrations of excreta within 30 meters of the water trough were significantly greater in the warm months of the year than during the cooler seasons. Oudshoorn *et al.* (2008) did not find localised patterns of excreta distribution and contributed it to high levels of active herbage intake by dairy cows during the brief grazing study period, with cows that spent most of their time indoors.

Pleasants *et al.* (2007) assumed spatial heterogeneity of urine patches and modelled the effects of two stocking densities, 450 cows/ha and 180 cows/ha in a rotational grazing system, on the distribution of urine depositions and N leached into ground water. They found that under the higher stocking density the frequency of overlapping urine patches increased exponentially. It was concluded that by adopting a grazing strategy with increased stocking density (from 180 cows/ha to 450 cows/ha) the N pollution of ground water would increase on average by 5% due to the increase in multiple overlapping urine patches.

Management Systems

Aland *et al.* (2002) reported an average of 16.1 defecations per cow per day in a tie-stall dairy system, while Phillips (1993) observed a range from 10 to 16 defecations per cow for grazing beef cattle. White *et al.* (2001) found lower numbers of defecations and urinations in grazing dairy cows than those reported by Aland *et al.* (2002) and no significant differences between Holsteins and Jerseys. Holstein dairy cows averaged 10.8±0.5 defecations per day compared with 10.9±0.5 for Jersey dairy cows. For the urinations, Holsteins averaged 9.0±0.6 while Jerseys averaged 8.7±0.6 urinations per day.

White *et al.* (2001) reported that the number of excretions that occur in a location is highly correlated to the time spent in that location. They found most excreta were deposited in the paddock (84.1% urine and 84.7% faeces) with no urination on the races and only 1.3% of defecations occurring there. Betteridge *et al.* (2007), observing set stocked grazing cattle and sheep, reported a higher concentration of urine patches near shelters and in stock camps. White *et al.* (2001) concluded that because of the correlation between excreta frequency and time spent in location, the deposition of faeces and urine can be effectively managed by changing grazing practices. For example, excreta loads at pasture can be reduced by keeping cows on a standoff area for a period of time.

Oudshoorn *et al.* (2008) investigated the effects of restricted grazing on urination and defecation frequency and the spatial distribution of excreta by dairy cows. Limiting grazing time did not influence the frequency of urination and defecation, although it had an effect on grazing behaviour while on pasture. Regardless of allocated grazing time, urine and faeces were uniformly distributed within the paddock, without notable hot-spots. Clark *et al.* (2010), studying the effects of restricted grazing on the location of urination events in intensively managed dairy cows, also found no differences in the number of urinations per day across treatments. This study indicated however, that the proportion of urinations located on pasture and races was reduced by a third when grazing was restricted to eight hours per day. This resulted in capturing 35% to 38% of total urinations when cows are kept on a stand-off pad when not grazing. The capture effluent should be re-cycled on the farm otherwise costly inputs of fertiliser are required to achieve nutrient balance.

1.3. Activity patterns

A time budget can be used to describe how an animal allocates its time to different behavioural activities over a 24-hour period (Fraser and Broom, 1997). Most animal species have distinct activity patterns (Lenthoed, 1977) and for the dairy cow some of the more common behaviours performed include grazing, ruminating and maintaining social structure with conspecific (Phillips, 1993) (Table 1.1).

Early studies (Table 1.1) have provided detailed description of how small groups of dairy cows kept on pasture allocate time to different behaviours over a 24-hour period. These studies also tried to identify possible factors that might influence the behaviour of dairy cows (such as pasture quality and lactation stage) and examined individual variations within groups. Recent studies (Table 1.1) describing detailed behaviour of dairy cows are more rare, as studies are mostly carried out to investigate particular factors and so only specific aspects of behaviour related to these factors are studied. Apart from the study by Botheras (2006), there are no other studies that investigate temporal and spatial patterns of behaviour of dairy cows managed under typical commercial conditions.

Table 1.1. Summary of key studies describing detailed behaviour of lactating dairy cows grazing pasture over a 24 h period.

Study	Number of Cows	Management / Treatment	Recorded Behaviour
Castle *et al.* (1950)	4	Rotational / Grass composition	Grazing; Ruminating; Standing; Lying; Loafing; Drink; Defecation; Urination
Hardison *et al.* (1956)	4	Rotational / Grass composition	Grazing; Ruminating; Standing; Lying; Loafing; Drink; Defecation; Urination
Phillips and Leaver (1986)	12 cows in a group of 48	Set-stock / Supplements	Grazing; Ruminating; Standing; Lying; Walking
Phillips and Hecheimi (1989)	18	Strip-grazed / SSH* & Milk yield	Grazing; Ruminating; Standing; Lying; Walking
Rind and Phillips (1999)	16	Rotational / Group size	Grazing; Ruminating; Standing; Lying; Aggression; Self-grooming; Allogrooming
Phillips and Rind (2002)	66	Rotational / Pasture allocation	Grazing; Ruminating (standing); Ruminating (lying); Lying; Standing
Botheras (2006)	20 cows in a group of 180	Rotational / Lactation stage	Grazing; Ruminating; Standing; Idling; Walking; Lying; Eliminating; Maintenance; Social
Oudshoorn *et al.* (2008)	60	Rotational / Pasture allocation	Eating; Lying; Standing; Walking; Defecation; Urination

* SSH: Sward surface height.

Factors affecting the behaviour of dairy cows

Several factors might influence the activity patterns of dairy cows and how they allocate their time to different behavioural activities. These factors, through their effect on behaviour, can significantly impact on the way dairy cows utilise paddocks and distribute nutrients. Factors can be broadly grouped into three categories, environmental factors, management factors and animal factors (Ganskopp, 2001; Botheras, 2006).

1.3.1. Environmental factors

Temporal patterns of behaviour

There are four main daily grazing periods in the behaviour of dairy cows. Cows grazed intensively immediately after morning and afternoon milking, and for two hours before midday and again around midnight (Hardison *et al.*, 1956). Similar grazing patterns were reported by Trotter and Lamb (2008) studying beef cattle, with peak grazing periods from 0600 to 0900 and from 1600 to 2000 and two smaller meal times around 1200 and 0000. O’Connell *et al.* (1989), Rook *et al.* (1994) and Gibb *et al.* (2002b) showed similar activity patterns, however, the grazing period at noon was less pronounced. Gibb *et al.* (1998, 2002a) reported that the longest meal of the day was the grazing period immediately between afternoon milking and dusk. These results are comparable to Penning *et al.* (1991), where sheep were observed to graze the longest in the four hours before sunset. The number and duration of grazing bouts has been found to differ between grazing periods. Daylight grazing times tend to have a large number of short bouts compared with the night, which had a smaller number of longer bouts (Phillips and Denne, 1988, Gibb *et al.*, 2002a). Orr *et al.* (2001) concluded that removal for milking, dusk and dawn have the greatest effect on determining beginning and ending of grazing in the dairy cow. The phase of the moon has also been found to have a significant effect on night grazing (Gibb, 2006). During nights when there is a new moon (i.e. dark phase) there was almost complete suppression of night-grazing activities in a herd of dairy cows at pasture.

There are four to five major rumination bouts in any 24-hour period for the grazing dairy cow (Hardison *et al.*, 1956). The largest proportion of rumination was observed during darkness (Hardison *et al.*, 1956; Gibb et al., 2002a) and rumination was highly correlated with lying down (Hardison *et al.,* 1956; O'Connell *et al.,* 1989). Dairy cows have been observed to have two major lying down periods; after the morning grazing period (Hardison *et al.,* 1956) or before afternoon milking (O'Connell *et al.,* 1989) and from sunset to sunrise (Hardison *et al.,* 1956; O'Connell *et al.* 1989).

Whereas grazing and rumination behaviours of dairy cows have been studied most extensively due to their significance to management and production, few studies have examined in detail the temporal patterns of behaviour such as drinking, social interactions and excreting in intensively managed dairy herds. Phillips (1993) suggested that most dairy cows drink either on their return to pasture after milking or during a grazing bout, mainly during the daylight hours. Hassoun (2002) also observed that cattle drank mostly during the day. O'Connell *et al.* (1989) reported that levels of grooming and agonistic interactions were low in dairy cows, and social interactions were mainly observed during the return from milking.

The pattern of defecation over the day was mainly determined by the grazing pattern, with cows most likely to defecate during grazing or after prolonged periods of lying down (Phillips, 1993). In contrast, dairy cows in tie-stalls have been observed to defecate and urinate most often during milking and feeding periods, and less during the resting time (Aland *et al.,* 2002). White *et al.* (2001) reported that 85% of dairy cows' excreta is deposited on pasture, with only 4.6 % of defecation and 3.1% of urinations deposited in the holding yard or in the milking shed. Similar results were presented by Clark *et al.* (2010) with 82% of total urinations recorded on pasture for intensively managed dairy cows.

Herd Synchronisation

Jarman (1974) suggested that social facilitation influences the pattern of behaviour of grazing herbivores. Clayton (1978) defined social facilitation as "an increase in the frequency or intensity of responses or initiations of particular responses, already in an animal's repertoire, when shown in the presence of others engaged in the same behaviour at the same time".

Behaviour synchronisation among animals is not always advantageous, but in certain contexts such as regulation of body temperature, reproduction and flight it may be important in maximising fitness (e.g. Clutton-Brock *et al.*, 1987; Clarke *et al.*, 1992 and Murphy and Schauer, 1996). Some synchronisation of behaviour between members of a group is essential for group cohesion (Krebs and Davis, 1993) and investigating behavioural synchronisation between animals may yield insight into differences in the organisation of behaviour between individuals (Engel and Lamprecht, 1997).

The simultaneous effect of environmental (e.g. weather, sunrise, sunset) and management (e.g. milking) cues on the behaviour of individual cows, along with the potential effect of social facilitation, often lead to behaviour synchronisation being observed in a group of grazing cattle (O'Connell *et al.*, 1989; Rook and Huckle, 1995 and Phillips, 1998). Similar findings have also been observed in grazing sheep (Rook and Penning, 1991) and free-ranging Przewalski's horses (*Equus przewalskii*) (Souris *et al.*, 2007).

Rook and Huckle (1995) reported that grazing, ruminating and standing activities of grazing dairy cows were all significantly more synchronised than random expectations. Grazing was more synchronised when compared with rumination and standing, especially during the daylight hours. Krebs and Davis (1993) put forward the hypothesis that the formation of groups afforded protection from predators, while Jarman (1974) suggested it is important for group cohesion that members of the group all grazed and rested synchronously. In contrast, synchronisation of ruminating activity would not be necessary for group cohesion and thus it is not as synchronised as grazing behaviour (Rook and Huckle, 1995).

Weather and Season

Kadzere *et al.* (2002) reviewed the literature on heat stress in lactating dairy cows in detail. They reported that dairy cows prefer ambient temperatures in the range between 5°C and 25°C (the thermoneutral zone). Deviations in ambient temperature below or above the thermoneutral zone cause the initiation of the thermoregulatory mechanisms to prevent or enhance heat loss from the animal. Thermoregulatory mechanisms include changes in behaviour (e.g. seeking shade, reduced feed intake, increased drinking) and physiological responses (e.g. increased respiration rate).

Seath and Miller (1946) investigated the influence of air temperature on the grazing behaviour of dairy cows in Louisiana (USA). Hot weather (30ºC) lowered the grazing time by one hour compared to cooler weather (22ºC). The time spent grazing differed with 1.9 hours spent grazing during the day and 6.5 hours spent grazing during the night in hot weather. In contrast, cows spent 4.5 hours grazing during the day and 4.7 hours grazing during the night in cooler weather. Kadzere *et al.* (2002) concluded that reduction in feed intake may be a result of a reduction in appetite due to elevated body temperature when cows are exposed to temperatures above the thermoneutral zone. Furthermore, ruminating behaviour was found to decrease and there was a prolonged retention of the feed in the gastrointestinal tract at temperatures above the thermoneutral zone.

Kendall *et al.* (2006) investigated the effects of providing artificial shade in summer on the behaviour of lactating dairy cows kept at pasture. Cows with access to shade preferred using it mainly during the mid-afternoon, while, in contrast, cows with no shade grazed more at this time. However, the total time spent grazing, standing and lying per 24 h did not differ between treatments. The study concluded that provision of shade was an effective method to reduce heat load in dairy cows under New Zealand summer conditions.

Young (1981) reported physiological change in cattle in response to exposure to temperatures below the thermoneutral zone. Cattle were observed to have increased heart rate, elevated thermoneutral resting metabolic rate, increased appetite and increased rate of passage of digesta. Behavioural changes were also noted, with cows seeking shelter or changing body orientation to minimize evaporative heat loss. Phillips (1993) also noted that heavy rain may stop cows grazing and cows may stand up, if lying down, during rain. Muller *at al.* (1996) and Fisher *et al.* (2003) concluded that cows may be inhibited from lying down in cold weather if the lying surface is muddy or wet. Redbo *et al.* (2001) reported that dairy heifers kept outdoors during winter at high latitudes were only observed to lie down in a dry, sheltered area. Dairy cows were also reported to spend more time lying at lower temperatures and lying time was associated with sun radiation and high wind speed. Redbo *et al.* (2001) concluded that lying reduces the proportion of the animal's body surface exposed to the cold and therefore represents a heat conservation strategy.

In contrast, Webster *et al.* (2008) investigated the exposure to wet and cold conditions on the behaviour of grazing dairy cows. The cows were exposed to wind and rain (WR) conditions with indoor shelter (I) provided for half of the cows. Cows spent a greater proportion of time standing and less time lying down when exposed to WR without I. However, it is not clear whether there were suitable lying areas for the cows exposed to WR, which may have affected these results. The proportion of time spent eating was also less in WR without I than with I, indicating that cows employed several behavioural responses to deal with adverse weather conditions. Tucker *et al.* (2007) also investigated the effects of shelter on the behaviour of dairy cows. Cows were divided into two groups where each group was switched between an indoor and an outdoor pen for a total of six weeks. The outdoor pen was equipped with sprinklers and fans to simulate continuous winter weather. When cows were kept outdoors, they spent less time lying down, and were more likely to spent time in lying and standing postures that reduced the amount of surface area exposed to rain and wind compared to when they were kept inside. Tucker *et al.* (2007) concluded that shelter mitigates the effects of winter weather on dairy cows.

Phillips and Leaver (1986) reported that season had an effect on total daily grazing time through changes in daylight hours between seasons and found that ruminating time increased through the grazing season (from spring to autumn). A similar increase in rumination time was also reported by Phillips and Hecheimi (1989). Rook and Huckle (1996) reported a strong positive relationship between day length and total grazing time, but no correlation between ruminating time and day length was found. In contrast, Phillips and Hecheimi (1989) and Linnane *et al.* (2001) found no significant difference in total grazing time over the grazing seasons.

Hessle *et al.* (2007) examined the effect of season on the behaviour of grazing heifers over 24 h. The cattle spent more time grazing in autumn (42.5% of the day) than in spring

(38.5%) and summer (38.9%) with efficiency of grazing (i.e. proportion of eating during grazing bout) increasing over the grazing period. They concluded that cattle most likely avoided grazing in darkness which is consistent with the theory that predation risk may affect foraging behaviour (Kreb and Davis, 1993), even if the risk of predation is only perceived.

It appears that the times of sunrise and sunset, and also removal of cows from pasture for milking, have been found to influence the temporal patterns of behaviour of many cow behaviour, and subsequently have an influence on the distribution of excreta around a farm. Furthermore, despite the conflicting results of the effect of weather and season on the behaviour of cattle, season and latitude in particular may affect dairy cow behaviour by influencing a number of other factors that directly affect cow behaviour, such as feed quantity and quality and stage of lactation.

1.3.2. Management factors

Time and frequency of pasture allocation

Grazed pasture is a relatively cheap source of feed for dairy cows. Rotational grazing, is the predominant means of pasture management on dairy farms in New Zealand. Under rotational grazing, cows are generally offered a fresh allocation of pasture after every milking.

Orr *et al*. (2001) investigated the difference in behaviour between cows allocated either fresh pasture in the morning (AM) or in the afternoon (PM). Although the time spent grazing was similar between the two grazing allocations, PM cows had a large meal of more than 4 h duration in the period up to sunset, whereas AM cows grazed for approximately 2 h. The evening meal of the AM cows was also shorter (3 h). Time spent ruminating differed between the two treatment groups, with the difference being attributed to a more rapid rate of digestion as a result of the PM cows' intake of herbage having a higher water-soluble carbohydrate concentration than that consumed by the AM cows. A similar experiment was carried out by Trevaskis *et al.* (2004), where the daily pasture was allocated either after morning or afternoon milking. Grazing activity was similar for both groups, however, the diurnal pattern of grazing differed between allocations. Grazing activity was 39% higher after allocation of new pasture after afternoon milking when compared with grazing activity of cows allocated new pasture after morning milking. Most likely, the timing of pasture allocation may not affect total time spent grazing, but may influence the temporal patterns of grazing behaviour.

Oudshoorn *et al.* (2008) investigated the effect of time-limited grazing allocation on Holstein-Frisian dairy cows. Cows were randomly allocated to three different treatments, with access to pasture during daytime for 4, 6.5 or 9 hours. Cows allowed pasture for 4 h moved more rapidly during time on pasture, moved longer distances per active hour and spent a higher proportion of the time eating than cows allowed longer time at pasture. Time spent lying and grazing was similar between treatments. Clark *et al.* (2010) allocated pasture to 48 primiparous Holstein-Friesian cows for 4 h after each milking (2x4), for 8 h between milking (1x8) and for 24 h (excluding milkings) (Control). Although time spent grazing was not recorded, the Control and 2x4 groups removed more pasture from the paddocks than the 1x8 group. Similarly to the findings of Oudshoorn *et al.* (2008), cows with the shortest allocation time on pasture (2x4) walked the greatest distance per day (average of 1.3 km/cow/day; $P < 0.01$). It appears that cows tend to adapt quickly to environmental changes, such as shorter grazing time, using their relatively short time for eating very effectively by moving around and seeking resources (Barrett *et al.*, 2001). Kennedy *et al.* (2009) supported that by reporting that restricted pasture access time resulted in much greater grazing efficiency. Cows with restricted grazing times (1 x 9 h, 2 x 4.5 h and 2 x 3 h grazing periods) spent a greater percentage of their time at pasture grazing (81, 81 and 96%, respectively) than cows left to graze for 22 h (42%).

Dalley *et al.* (2001) investigated the effect of frequency of fresh pasture allocation to dairy cows in south-eastern Australia. Cows were given a daily allowance of herbage at one time or in six equal feeds. The different grazing allocations did not have a significant influence on the total grazing, ruminating or resting times. However, the frequency of grazing allocation had an effect on the temporal grazing patterns, as cows decreased the proportion of daylight hours spent grazing when smaller pasture allocations were offered more frequently. Abrahamse *et al.* (2007) also studied the effect of frequency allocation of pasture to grazing dairy cows. Cows were offered fresh pasture either every day or every four days. Grazing time (average 562 min/d) and ruminating time (average 468 min/d) were similar between treatments, but grazing time increased (549 to 568 min/d), while ruminating time decreased (471 to 450 min/d) within periods in the four day treatment. These effects are similar to the effect observed when offering a set pasture allocation at different times.

Pasture characteristics

Phillips and Hecheimi (1989) reported that grazing time increased at low herbage height (sward surface height) (4 cm) compared to an herbage height of 8 cm. Similarly, Rook (2005) observed an increase in grazing time with a decrease in sward height. Gibb *et al.* (1999) found that time spent grazing significantly increased as sward height decreased when offering grass at sward heights of 5, 7 and 9 cm. Phillips (1993) concluded that herbage height most likely determines bite size and bite mass, and that a higher sward promotes a greater rate of intake per bite reducing the grazing time required to achieve optimum level of intake. Barrett *et al.* (2001) investigated the effect of declining sward height on the pattern of herbage intake and bite dimensions in rotationally grazed dairy cows. It was reported that bite mass declined with declining sward height, however, intake behaviour was variable. Similar results were reported by Rook (2005) with low bite mass at low sward height.

Orr *et al.* (2001) studied the effect of DM and water-soluble carbohydrate concentrations in the grass on grazing behaviour of dairy cows given a grass allowance in a strip-grazing system after either morning or afternoon milking. The DM and water-soluble carbohydrate concentrations in the grass were higher in the afternoon. Both groups spent similar total times grazing, although the group with afternoon grazing allocation had a longer evening meal (>4 h duration) compared with cows receiving their grazing allocation in the morning (2-3 h). Rook (2005) also reported that dairy cows eat a larger meal in the afternoon when sugar concentration in leaves is high. Furthermore, cows with free choice eat around 70% clover and 30% ryegrass, selecting more clover in the morning and more ryegrass in the evening. Marotti *et al.* (2002) concluded that eating clover ensures a more rapid intake of nutrients compared with ryegrass and this may be behaviourally important in the morning. Dry matter and soluble carbohydrates accumulate in grass during the day, and grass has a higher fibre concentration than clover. Therefore, eating more grass in the afternoon when time can be spent ruminating during the night may be preferable to the animal and consistent with maximising fitness (Marotti *et al.*, 2002).

Phillips and Hecheimi (1989) reported that in early lactation ruminating time increased as sward height increased, but in later lactation there was no effect of sward height on ruminating behaviour. Gibb *et al.* (1997) also found that time spent ruminating increased with increase in sward height, but Rook *et al.* (1994) did not find any effect of sward height on rumination behaviour. What few studies are available, indicate that there is no consistent effect of sward height on rumination behaviour.

Few studies have also investigated the effect of herbage allowance (the amount of above-ground herbage DM offered per cow per day (kg DM/cow/day) on the behaviour of dairy cows. Wales *et al.* (1999) reported that cows spent less time grazing and more time idling at the lowest of four herbage allowances (20 vs. 35, 50 or 70 kg DM/cow/day). In another study, cows were observed to graze for less than 8.7 h/day during all herbage allowance treatments (20, 30, 40, 50, 60 and 70 kg DM/cow/day) (Moate *et al.*, 1999). There was an increase in intake, however, achieved by the increase in the rate of herbage intake from 1.5 to 2.2 kg DM/h for herbage allowance of 20 and 70 kg DM/cow/day, respectively. Rook (2005) and Dalley *et al.* (1999) concluded that high daily herbage allowance may improve intake, but it can also lead to poor utilisation with more herbage left after grazing. Dalley *et al.* (1999) reported no significant differences in time spent grazing when six herbage allowances from 20-70 kg DM/cow/day were compared. Similar results were presented by Bargo *et al.* (2002) where two herbage allowances (25 vs. 40 kg DM/cow/day) did not have an effect on time spent grazing. On the other hand, rumination and resting behaviours were affected by herbage allowance (Dalley *et al.*, 1999). These two behaviour parameters decreased in duration as herbage allowance increased and cows offered the lowest herbage allowance spent significantly more time ruminating and resting than cows offered the two highest herbage allowances. On the other hand, Wales *et al.* (1998, 1999, 2001) and Bargo *et al.* (2002) found no effect of herbage allowance on the time spent ruminating, standing or lying.

Few studies have looked into the effect of herbage mass (the weight of above-ground herbage DM offered (t DM/ha) on the behaviour of dairy cows. Wales *et al.* (1999) found no significant effect of two herbage masses (3.1 and 4.9 t DM/ha) on the time spent grazing, lying, standing and ruminating by lactating dairy cows. In contrast, Stakelum and Dillon (2004) observed an increase in grazing time with a decrease of herbage mass when three herbage masses (3064, 3472 and 3515 kg DM/ha) were compared.

Herbage allowance appears to influence both grazing and ruminating behaviour, but results are somewhat inconclusive. In general, grazing time was not affected or decreased at low herbage allowance. Factors such as season, stage of lactation, climate and pasture-type may contribute to the inconsistencies between different studies. It is apparent that pasture characteristics have an effect on some aspects of the behaviour of dairy cows and need to be considered when investigating activity patterns, especially when examining grazing and rumination behaviour and any subsequent excreta distribution.

Feeding supplements

Studies indicate that offering supplements to dairy cows at pasture has an effect predominantly on time spent ruminating. Phillips and Leaver (1986) and Phillips and Hecheimi (1989) reported an increase in ruminating times for cows offered silage, compared to cows grazing without supplements. Phillips (1993) concluded that rumination time is influenced by the level of rumination required for a specific diet and depends mainly on the fibre content and DM of the offered diet. Thus, the effect of forage supplements on ruminating behaviour could also be expected to affect the time allocated to other behaviours, such as grazing. Phillips and Hecheimi (1989) found grazing time was greater for cows not fed silage, particularly when cows grazed on short herbage. Neither number of grazing bouts nor time spent lying were significantly affected by feeding silage.

Rook *et al.* (1994) studied the effect of offering 0 to 4 kg of concentrate feed to dairy cows in early and mid lactation. In the early lactation, grazing times on two higher swards were similar between supplemented and not supplemented cows. However, on the lowest sward, grazing times were significantly different (765 min/24h – not supplemented and 535 min/24h – supplemented). Feed supplementation also had an effect on rumination time within a sward height treatment with supplemented cows ruminating for longer. Offering supplements later in lactation did not have a significant effect on grazing and ruminating behaviour within a sward height. Similar results for cows in early lactation were reported by Pulido and Leaver (2001) when cows were fed grain-based concentrates at levels of 0 to 6 kg/day. In contrast, Gibb *et al.* (2002a) investigated the effect of six different levels of grain-based concentrates (0 to 6 kg/day) on the behaviour of dairy cows at pasture. The level of supplements offered did not have a significant effect on time spent grazing or ruminating. Hameleers *et al.* (2001) also reported no significant effect of supplementary feed on the time spent grazing and ruminating. They fed cows with either low energy/low degradability (high straw) or with high energy/high degradability (low straw) feed supplementation offered for 1 h after each milking.

Bargo *et al.* (2003) concluded that increasing DM intake of concentrate reduces average grazing time by 12 min/day for every kilogram of concentrate. It is uncertain whether supplements have a greater effect on grazing or ruminating behaviour, however, it is reasonable to assume that the fibre content of the supplement offered is likely to influence rumination behaviour and thus time allocated to other behaviours.

1.3.3. Social factors

Group size

Rind and Phillips (1999) found that group size (4, 8 and 16 cows per group) had an effect on the standing, lying, ruminating and social behaviour of dairy cows. Kondo *et al.* (1989) studied the social behaviour of dairy cattle in groups of eight to 91 animals and found that the number of agonistic encounters per hour was positively correlated with group size. These studies examined small groups of dairy cows and the applicability of the results to much larger groups of cows is questionable. Average herd size under New Zealand commercial conditions is currently estimated to be around 350 cows (New Zealand Dairy Statistics, Dairy NZ, 2008). Therefore, the possible effects of large group size on the time budgets of grazed dairy cows are unknown.

No further studies examining the effect of group size on the behaviour of dairy cows could be found. Two experiments investigated the effect of variable stocking densities on the behaviour of dairy cows. Stockdale and King (1983) reported an increase in grazing time per cow as stocking density increased, while ruminating increased as stocking density decreased. Resting behaviour was found not to be affected by stocking density. Taweel *et al.* (2006) found changes in time spent grazing under two stocking densities, however, the differences were attributed to the effect of weather and management on the grazing times. Woodward *et al.* (2008) found no stocking density (16, 32, 64, 128 and 192 cows ha/day) effect on food intake per cow, while travel time per cow increased with increase in stocking density in an optimal foraging model. Finally, Tomkins *et al.* (2009) examined the effect of stocking rate (4 ha v. 8 ha per animal equivalent of 450kg steer) on the travel distance of beef cattle. The study found no significant differences for distance travelled per day between high and low stocking rates.

One reason why group size and stocking density may influence behaviour relates to increased competition for resources in large groups where resources may be limited (Krebs and Davis, 1993). Another suggestion relates to the level of perceived danger of predation where individual animals may perceive themselves to be under greater danger from predation than they might be as part of a large group. Individual animals in smaller groups may spend more time on vigilance behaviour than animals in larger groups and hence there may be differences in their time budgets (Krebs and Davis, 1993; Rind and Phillips, 1999). Rind and Phillips (1999) suggested that the action of social facilitation on the synchronicity of behaviour in groups may also be another factor influencing the effect of group size on behaviour.

Genetic merit, milk yield and breed

Arave and Kilgour (1982) found no difference in grazing time between morning and afternoon grazing periods for cows of low and high genetic merit. There was an exception during the late lactation stage, when cows of high genetic merit grazed for longer. In contrast, Bao *et al.* (1992) reported high genetic merit cows grazed for a longer time per day than low genetic merit cows. The magnitude of the differences in grazing time was small and it was suggested that this might indicate a difference in grazing or metabolic efficiency between high and low genetic merit cows. Bargo *et al.* (2003) suggested that high-yielding/high-merit cows grazed for longer, had more bites per day and had a higher rate of intake than low producing cows.

On the other hand, Phillips and Leaver (1986) found no significant relationship between milk yield and grazing time and Phillips and Hecheimi (1989) found no effect of milk yield on daily grazing time. In contrast, Pulido and Leaver (2001) found that cows with higher initial milk yields had longer grazing times than cows with lower initial milk yield. Phillips and Hecheimi (1989) reported that high yielding, high genetic merit cows were observed to spend more time ruminating than lower yielding, lower genetic merit cows.

Arave and Kilgour (1982) implied that cows with higher milk yields may be able to achieve greater intake in an equivalent time period and also have greater feed efficiencies than lower yield cows. This would support the findings of no effect of milk yield or genetic merit on grazing time. In appears that higher yielding and higher genetic merit cows may increase bite rate and bite size to achieve a higher intake rate without increasing grazing time (Bao *et al.*, 1992; Pulido and Leaver, 2003). Furthermore, increased time spent ruminating may increase food digestibility, thus supporting increased milk yield without increased grazing times (Phillips and Hecheimi, 1989).

McCarthy *et al.* (2007) investigated the differences in grazing behaviour between three strains of Holstein-Friesian dairy cows (high production North American (HP), high durability North American (HD) and New Zealand (NZ)) managed under three different grass-based systems (i.e. high allowance, high concentrate and high stocking rate). They reported that the strain of cow and feeding system had highly significant effects on grazing behaviour, DM intake and milk production. The NZ strain had the longest grazing time while the HD strain had the shortest. Similarly, Senn *et al.* (1995) found differences in the feeding behaviour of lactating Holstein-Friesian, Jersey and Simmental dairy cows housed indoors.

Conversely, O'Driscoll *et al.* (2009) found no significant effect of breed on the time spent feeding, ruminating and lying when comparing the behaviour of Holstein-Friesian and Norwegian Red dairy cows. However, Holstein-Friesian cows had a higher bite rate and fewer mastications while feeding than Norwegian Red cows.

Stage of lactation, age and physical condition

Phillips and Leaver (1986) examined the behaviour of an early and a late lactation group of cows over 24 hours. They reported that the cows in early lactation spent longer grazing and eating silage than cows in late lactation. Cows in early lactation also spent longer standing and standing-ruminating, and less time lying and lying-ruminating, than cows in late lactation. In contrast, Krohn and Munksgaard (1993) observed cows on days 60, 150 and 240 of lactation and found stage of lactation had no significant effect on lying time. However, cows were only observed during the day and hence compensatory behaviour may have occurred outside the observation time.

Nielsen *et al.* (2000) and Chaplin and Munksgaard (2001) reported similar results to those found by Phillips and Leaver (1986). Chaplin and Munksgaard (2001) found that cows in early lactation spent less time lying than cows in late lactation and attributed these differences to increased udder discomfort for cows in early lactation. Nielsen *et al.* (2000) concluded that stages of lactation affected a number of behavioural categories and the most marked changes occurred within the first 3 months after calving.

Phillips and Leaver (1986) found no significant difference between adult cows and first lactation cows in grazing times, although first lactation cows were observed to ruminate more whilst lying down compared to adult cows. Adult cows were also found to ruminate longer in total than first lactation cows. Singh *et al.* (1993) reported the lying and ruminating behaviour of first lactation and adult dairy cows on pasture. They found that first lactation cows spent less time lying, but more time ruminating in total per day when compared with adult cows. These differences, however, where not statistically tested. Chaplin and Munksgaard (2001) studied the lying behaviour of first, second and third lactation cows in tie-stalls and found no significant differences between treatments in total lying time. Similar results were also reported by Krohn and Munksgaard (1993) and Rook and Huckle (1996).

Botheras (2006) reported some differences in the time spent lying between cows in peak lactation and cows in mid lactation (7.7 h/day and 9.5 h/day respectively). Ruminating time increased with lactation stage, while the time spent grazing showed a slight decrease from peak lactation to mid lactation period (9.7 h/day to 8.1 h/day respectively).

Several studies have demonstrated that deterioration in the physical condition of cows can affect behaviour, milk yield and reproductive efficiency of dairy cows (Hassall *et al.*, 1993; Sauter-Louis *et al.*, 2004; Bach et al., 2007).

Hassall *et al.* (1993) studied the behaviour of lame and normal dairy cows during summer grazing. The lame cows were found to lie down for longer and grazed for shorter periods than normal cows in the paddock. All cows ruminated for longer periods when lying than when standing, but the difference was significant only for the lame cows. Lame cows were also found to have significantly lower bite rates than normal cows. In addition, lame cows entered the parlor consistently later than non-lame cows. Sauter-Louis *et al.* (2004) found similar trends, where lame dairy cows were most likely to be found in the last quarter of the herd during milking.

Bach *et al.* (2007) investigated the effect of lameness on the behaviour and productivity of Holstein dairy cows kept in loose-housing conditions and milked with an automatic milking system. The time spent eating and the number of daily meals decreased with increasing locomotion score, where locomotion score was associated with more lameness. In addition, lame cows visited the automatic milking system less often than non-lame cows, thus, decreasing milk yield.

Social structure and milking order

The consistent voluntary order of entry of a group of dairy cows into a milking facility from one milking to the next has been termed the milking order (Botheras, 2006). Several studies have investigated or otherwise mentioned the phenomenon of the formation of a milking order in a herd of dairy cows (e.g. Guhl and Atkeson, 1959; Dickson *et al.*, 1967; Soffie *et al.*, 1976; Tanida *et al.*, 1984; Rind and Phillips, 1999; Sauter-Louis *et al.*, 2004, Botheras, 2006).

Soffie *et al.* (1976) examined the milking order in a group of 34 to 50 cows over 13 months. The milking order in each observation period was reported to be constant over the 13 months of observations. Rathore (1982) studied the milking order in a herd of 45 cows over six afternoon milkings. The consistence of milking order over any two days was highly significant. Arave and Kilgour (1982) observed the milking order of 32 cows during five-day periods over 6 months of lactation and reported repeatability of milking order correlation coefficient of 0.40. Ferguson *et al*. (1967) concluded that cows develop a consistent milking order and maintain it over time. Kennedy and Chaplin (2004) recorded the milking order in five commercial herds in south-east Australia, where the average herd size was 280. While four of the herds were reported to have similar high consistency, in the largest herd the consistency was much lower. Kenedy and Chaplin (2004) also reported significant variation in milk order consistency between individual cows within each herd. It was suggested that consistent milking order might not develop in larger herds, but some cows within the herd may be consistent in their milking order position. In contrast, Botheras (2006) found a consistent milking order in large, commercial dairy herd kept on irrigated pasture in south-western Victoria (Australia).

Botheras (2006) investigated the effect of milking order on the behaviour of grazing dairy cows in detail. Milking order did not have a significant effect on grazing behaviour, but cows entering for milking later were observed lying down less than cows entering for milking earlier. Cows higher up the milking order were reported to ruminate and idle more than cows lower on the milking order.

Rathore (1982) found a significant linear relationship between milking order and milk yield in six herds ranging from 42-312 cows. It was reported that cows entering earlier tended to yield more than cows entering later. Similarly, Rind and Phillips (1999) found that milking order and milk production were significantly correlated, with higher production cows entering earlier in the milk order. It has been suggested that reducing discomfort when being milked presents stronger selection pressure influencing milking order. However, several studies have failed to find any relationships between milking order and milk yield (Soffie *et al.*, 1976; Arave and Kilgour, 1982; Tanida *et al.*, 1984; Botheras, 2006).

Guhl and Atkeson (1959) investigated the relationship between social dominance and milking order. They reported a positive correlation (r = 0.52) between dominance rank and milking order. On the other hand, Soffie *et al.* (1976) found a lower (r = 0.36) correlation between milking order and dominance rank. Fraser and Broom (1997) suggested that cattle can only recognise 50-70 other group members. Therefore, in groups too large for individual recognition, failure to establish hierarchy would eliminate dominance as a factor influencing milking order. Phillip and Rind (2002) reported that cows high in the dominance order were more likely to enter the milking parlour first, but not to begin grazing first, while higher ranking cows produced more milk than subordinates. They also reported that dominant cows had higher pasture biting and silage chewing rates.

Hassall *et al.* (1993) reported that lame cows entered the milking shed to be milked significantly later than non-lame cows of similar lactation stage. Gadbury (1975) and Botheras (2006), on the other hand, observed that older cows were more likely to be in the last half of the milking order and suggested that older cows are more likely to have problems with their feet and experience difficulty walking. Sauter-Louis *et al.* (2004) suggested that prior experiences in the milking facility may contribute to the position and consistency of individual cows in the milking order. Further, Sauter-Louis *et al.* (2004) found cows that walked or were milked in the last quarter of the herd were much more likely to have lameness. Several studies have found that lameness is more prevalent in cows in the last 5% of the milking herd order (Hassal *et al.*, 1993; Singh *et al.*, 1993; Sauter-Louis *et al.*, 2004). Finally, Sambraus and Keil (1997) and Hopster *et al,* (1998) concluded that milking order may be influenced by habits rather than by measurable factors.

1.4. Precision Agriculture and Livestock Management

Global positioning system (GPS) technology is increasingly applied in livestock science and it is central to precision farming and resource management. Global positioning system technology is already used commercially to improve management in crop agriculture (e.g. Salyani *et al.*, 2006), while recent technological advances have led to the development of lightweight GPS collar receivers suitable for monitoring livestock (Schlecht *et al.*, 2004). Because GPS based tracking devices have been found to have little effect on the behaviour of medium to large animals (Rutter *et al.*, 1997), the technology offers great potential for investigating livestock behaviour under commercial conditions. Earlier methods of monitoring animals in large groups or over long periods of time relied on human observation of natural or artificial features (Turner *et al.*, 2000). Data generated via these methods, however, can be prone to errors associated with factors such as observer fatigue and estimating individual spatial positions using map grid alone. Furthermore, external factors such as weather can prevent continuous observations and the proximity of an observer to a monitored animal can have an effect on its behaviour. Several studies have shown that GPS monitoring can provide efficient and accurate information on different aspects of animal behaviour (e.g. Rutter *et al.*, 1997; Rempel and Rodgers, 1997; Ganskopp, 2001; Schwager *et al.*, 2007; Trotter and Lamb, 2008). By using precision animal location recordings in conjunction with a geographic information system (GIS), animal distribution and movement can be related to landscape features such as topography and forage variability. Understanding the effect of spatial and temporal variability of animal and landscape features on foraging behaviour and pasture consumption provides potential to modify pasture management and improve efficiency of utilisation.

GPS for Animal Monitoring

GPS utilises 24 satellites that circle the earth in six, 12-hour orbits where five to 12 satellites are visible from any point on earth at any one time. The system is known as Navigation by Satellite with Timing and Ranging (NAVSTAR) and was launched and operated by the US Department of Defence in 1978 (Hurn, 1989). The satellites generate and transmit a precisely timed radio signal which in turn is monitored by four ground-based stations located in the United States of America. These control base stations continuously check the health and position of the satellites and upload any necessary corrections to the satellites. Global positioning system units receive information from the satellites and convert satellite signals into location estimates (Moen *et al.*, 1997; Rempel and Rodgers, 1997; Turner *et al.,* 2000).

One of the concerns in using GPS to monitor animal behaviour is the potential of the effect of system error on the data. The accuracies of GPS receivers are related to factors that influence performance such as problems with satellite clocks, satellite orbits and GPS receiver error. The ionosphere and the troposphere can distort satellite radio waves by slowing them down as they pass through, causing atmospheric distortion errors (Hurn, 1989). Satellite radio signals could also be reflected off large objects, thus causing multipath errors (Hurn, 1989). Several studies have also reported that topography, overhead canopies and adjacent structures can cause errors (Moen *et al.*, 1996; Rempel and Rodgers, 1997; Di Orio *et al.*, 2003). Moen *et al.* (1996) showed increased time to location fix with the increase of canopy cover. Similar results were presented by Remel and Rodgers (1997), who reported a reduced rate of successful GPS location fixes with increasing tree cover.

One way to improve the accuracy of a GPS receiver is to use differential correction (DGPS) to minimize the effects of atmospheric distortions and eliminate satellite clock errors (Moen *et al.,* 1997; Rempel and Rogers, 1997; Hulbert *et al.*, 1998; Hulbert and French, 2001; Schlecht *et al.,* 2004). A stationary receiver (base station) is placed at a known, previously surveyed location and takes position readings simultaneously with a roving GPS receiver. Base station receivers need to be high accuracy systems such as real-time kinematic GPS (RTK). Although base station receivers calculate location positions that will not exactly correspond to the surveyed location due to error, the receiver can calculate the magnitude of error involved based on the known coordinates of the surveyed location. In most cases the errors calculated by the base station receiver can be corrected for any roving GPS receivers, thus removing these errors from location fixes (Parkinson *et al.,* 1996).

In addition to the factors described above, the accuracy of the GPS receiver also depends on the number of visible satellites and the way they are distributed in the sky (Hurn, 1989). If the satellites are distributed evenly across the sky, the satellite geometry is considered "good". The quality of satellite geometry is described in terms of Position Dilution of Precision (PDOP, 3-D) or Horizontal Dilution of Precision (HDOP, 2-D). A two-dimensional record (HDOP) is compiled with data from a minimum of three satellites, and an elevation measure is not attempted. A three-dimensional record (PDOP) includes a measure of elevation and requires data from a minimum of four satellites (Ganskopp and Johnson, 2007). When the satellites are far apart in the sky, the triangulation error is small and Dilution of Precision (DOP) values are low, while clustered satellites lead to a large triangulation error and high DOP values (Hurn, 1993; Moen *et al.,* 1997; Rempel and Rodgers, 1997; Schlecht *et al.,* 2004).

Absolute errors are referred to as circular error probable (CEP) and are expressed as radial distance of error locations from the true location. The CEP is a radius of a circle that contains the stated percentile of points around a known location (Turner *et al.,* 2000). For example, CEP calculated at two degrees of freedom is determined by graphically locating all data points located in the 98th percentile (98% CEP). Global positioning system receivers used by Moen *et al.* (1997) to study moose (*Alces alces*) movement and habitat use, showed 50% CEP of 28.2 m and 95% CEP of 73.7 m. The same readings with DGPS showed values of 4 m at 50% CEP and 10.6 m at 95% CEP. Rempel and Rogers (1997) found that 95% of uncorrected readings had error less than 125.6 m, but with DGPS the 95% CEP was reduced to 7.5 m.

A good number of assessments of GPS error focus on the accuracy of individual coordinates relative to their true positions rather than measures of distance. Most GPS devices, however, tend to have better dynamic accuracy than static accuracy. The dynamic or pass-to-pass accuracy is expressed as the repeatability of measurements under dynamic conditions. The more precise a device is, the more repeatable the measurements will be (Werner *et al.*, 2003).

Another point to consider when examining GPS accuracy is the relationship between GPS performance and GPS location fix intervals. Mills *et al.* (2006) studied timber wolves (*Canis lycaon*) and investigated the GPS performance under varying fix intervals (i.e. the amount of time between location fixes). In the study, three GPS transmitters were scheduled to obtain one location every 0.25, 1.5, 2, 6 and 12 hours. Mean fix acquisition time and mean fix success rate were calculated at different fix intervals. Results indicated that mean fix success rates decreased and location acquisition times increased with increasing fix intervals. Mills *et al.* (2006) concluded that the shortest possible fix intervals should be used when studying fine-scale animal movements, although this will reduce the longevity of the GPS transmitter. Longer fix intervals were considered adequate for data needs such as home range analysis.

Swain *et al.* (2008) investigated the effect of different GPS fix intervals on the ability to accurately predict animal location and patch selection. The study showed that a fix interval of 1 hour, for an area of 1 ha gives a 70% error for predicting patch selection. By obtaining a fix every 10 seconds with a patch area of 100 m^2 the prediction error was calculated to be approximately 1 %. Swain *et al.* (2008) established the importance of having GPS fix rate increase as patch area decreases to accurately predict animal location.

GPS and Other Sensors

In principle, it should be possible to determine animal activity from the distance between successive GPS locations, where for example short, medium and long distance correspond to rest, grazing and travelling respectively (Ungar *et al.*, 2005). Ungar *et al.* (2005) suggested that distances travelled between 200 and 300 meters per hour coincide with travelling/grazing behaviour. Lamb *et al.* (2008) observed similar levels of movement between 0600 – 0900 hours and 1600 – 2000 hours, a time normally associated with peak livestock grazing activity (Roath and Kruger, 1982). Nevertheless, this might prove unreliable due to the inherent level of GPS location error discussed above. Variability in livestock movements may also defeat such an approach (Moen *et al.,* 1996; Turner *et al.*, 2000; Ungar *et al.*, 2005). Some GPS collars, however, incorporate motion sensors that register activations over a specific period of time as indices of activities (Schwager *et al.*, 2007), while other GPS units incorporate accelerometers to aid activity classification (Ungar *et al.*, 2005). Motion sensors normally record the horizontal and vertical angle of the animal's head. Head angles are measured in degrees from a reference position corresponding to the head being level with the backbone of the animal while looking straight ahead (Schwager *et al.*, 2007). Head angles can be indicative of particular animal behaviour. For example, while foraging the head of a cow is likely to be angled down towards the ground and during resting it is likely to be looking straight ahead or somewhere else (Anderson, 2006).

In order to calibrate predictive models to differentiate among activities, derived from motion sensors, it is important to carry out synchronised visual observations of the collared animal. Turner *et al.* (2000) examined the possibility of using field observations, GPS fixes and motion sensor output to classify animal behaviour into grazing and not grazing. The analysis correctly classified 94.8% of active (grazing) data records and 91.2% of inactive (not grazing) data records. Conversely, Ganskopp (2001) examining the relationships between observed animal activity and the linear distance between GPS fixes and motion sensor counts, showed that activity did not correlate in a consistent manner with distance and motion sensor data. Schlecht *et al.* (2004) compared activity classification results from human observations with those determined from analysis of GPS fixes and found that the two were in agreement for 71% of the data. Ungar *et al.* (2005) used field observations, GPS fixes and acceleration data from a motion sensors to determine cattle activity. The data indicated that distance between adjacent GPS fixes was not a good indicator of animal activity, but combining motion sensor data with the distance data greatly improves the prediction of animal activity. Schwager *et al.* (2007) used K-mean classification algorithms and data from GPS fixes and motion sensors to successfully enable animal activity classification into two broad categories, active and inactive, without the use of field observations.

Apart from motion sensors, devices using accelerometer technology are now available and allow the accurate monitoring of cattle behaviour. McGowan *et al.* (2007) carried out a study to validate the use of IceTag3D® Activity Monitors to remotely determine the behaviour of dairy cows. The IceTag3D® determines the proportion of time an animal is lying, standing or active and also generates a count of steps taken in a given period (IceRobotics, Scotland, United Kingdom). Behaviour observations were carried out by observers in the field and data were compared to that gathered by the activity monitors. For example, it was found that the IceTag3D® recorded 100% of lying bouts and all to within ± 1 minute of the observers' recorded observations. Although the study indicated that activity monitoring technology can be used to remotely measure behaviour, its potential if incorporated with GPS was not investigated. Trenel *et al.* (2009) also carried out a study to validate IceTag3D®s and concluded that the devices accurately measured high-prevalence behaviours such as standing and lying, and measured less accurately the low-prevalence behaviours such as moving. Aharoni *et al.* (2009) did incorporate GPS transmitters with IceTag3D®s while studying the differences in grazing behaviour and energy costs of activity between two types of beef cattle. The scope of the study was to aid behaviour activity monitoring that enables more consistent linking of activity data to position in the field, although the output data from the two devices were not examined for any relationships.

Urine sensors are a relatively new device developed by AgResearch, New Zealand to record urination events in cattle and sheep (Betteridge *et al.*, 2010b). The urine sensors are deployed together with GPS loggers to determine urine patch distribution in grazing systems (Betteridge *et al.*, 2008, 2010b). Clark *et al.* (2010) used GPS and urine sensors to successfully study the effect of reduced grazing access on the intake, production, welfare and excretory behaviour of dairy cows. Betteridge *et al.* (2008) deployed GPS and urine sensors on grazing sheep to study the impact of animal behaviour on the potential for N leaching and nitrous oxide emissions.

GPS Application in Animal Research

Only one study (Clark *et al.,* 2010) was found where GPS technology has been used to study the behaviour of dairy cows kept under intensive commercial grazing conditions. However, there have been numerous studies where GPS has been used to investigate the behaviour and habitat use of beef cattle and other animal species (e.g. Grigg *et al.,* 1995; Schlecht *et al.,* 2004; Tomkins and O'Reagain, 2007). Global positioning system has been of particular importance to ecologists and wildlife biologists, enabling the study of free-ranging animals over large areas and prolonged time periods. Over the last decade many species have been monitored using GPS, including elephant (*Loxodonta africana*) (Blake *et al.*, 2001), moose (Girard *et al.,* 2002), elk (*Cervus elapus*) (Biggs *et al.,* 2001), camel (*Camedus dromedarius*) (Grigg *et al.,* 1995) and caribou (*Rangifer tarandus*) (Johnson *et al.,* 2002a and b).

Global positioning system collars have also been incorporated in the study of ecology and management of grazing systems and are particularly useful in examining the interactions between domestic grazing animals and their environment. For example, Rutter *et al.* (1997) used GPS tracking to study grazing preferences in hill sheep in the United Kingdom, while Hulbert *et al.* (1998) researched the ecology and management of grazing systems using sheep with GPS collars. Pepin *et al.* (2004) assessed real daily distance travelled, by tame red deer (*Cervus elephus*), using recorded GPS locations, as a new tool to study habitat use by grazing animals. Schlecht *et al.* (2004), using Zebu (*Bos indicus*) cows, demonstrated the potential to estimate daily activity budgets and hourly activity patterns from GPS recordings. Unger *et al.* (1995), on the other hand, used GPS positions and accelerometer data from cattle to infer states of activity. Ganskopp (2001) used GPS receivers to evaluate the efficiency of salt and water to manipulate cattle distribution within paddocks. More recently, Brosh *et al.* (2006) used GPS technology to provide experimental and statistical tests for estimating the energy costs of behavioural activities in grazing cattle. Tomkins and O'Reagain (2007) utilized GPS receivers to quantify cattle distribution and grazing preferences in large, heterogeneous paddocks in northern Australia. Trotter and Lamb (2008) employed GPS tracking to monitor interactions between grazing Angus cattle, plant communities and soil characteristics in a livestock system, while Putfarken *et al.* (2008)

used GPS to study grazing preferences and site use in a mix-species grazing system where cattle and sheep were kept together. Finally, Ganskopp and Bohnert (2009) used GPS technology to investigate the relationship between landscape nutrition and cattle distribution in rangeland pastures. While Haan *et al.* (2010) used GPS equipment to monitor animal movement in relation to best management practices to protect sensitive riparian areas.

It is apparent there is a large potential for using precision tools like GPS and other sensors in domestic animal studies. These technologies enable us to remotely carry out extensive monitoring programmes where animals are less affected by human activity and relatively large, accurate data sets can be generated in a commercial setting.

1.5. Conclusions

The grazing and excretion activities of grazing animals have a major impact on the recycling of essential elements (nutrients) required for pasture growth. Factors which influence cow grazing and resting behaviour, and the spacial location of these activities have a key influence on whether nutrients are distributed to the grazing area in a uniform or non-uniform manner. The most important factors to impact dairy cow behaviour are environmental factors (e.g. temporal patterns and weather) and management systems (e.g. pasture allocation and stocking density). Although numerous studies have been conducted to study the influence of management on herd behaviour with respect to feeding and milk production, few studies have examined relationships between grazing, resting and urination, and none have studied these aspects on a large commercial dairy herd.

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 allows a more precise study of animal behaviour and the spatial distribution of urine by livestock. Global positioning system collars and IceTag3D$^{®}$ sensors allow us to monitor the movement of animals and to study grazing and resting patterns, while urine sensors can help us identify locations of urine deposits. 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.

Therefore, the objective of this project was to:

- Quantify urine patch density in a New Zealand dairy system using tracking and sensor technologies.

Chapter Two: Investigation into the effects of temporal and environmental factors on the urination behaviour of dairy cows

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2.1. 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 is particularly prevalent 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).

Several factors affect patterns of livestock distribution in space and time, and consequent dispersal of excreta. Environmental and animal factors such as seasons (White *et al.*, 2001), time spent on pasture (Oudshoorn *et al.*, 2008; Clark *et al.*, 2010), gateways (McDowell, 2006), water troughs (White *et al.*, 2001; McDowell, 2006), the paddock's physical characteristics and stock camps (Betteridge *et al.*, 2007, 2010a) can all have an influence on animal distribution and nutrient re-distribution patterns.

Only very few studies have focused on the urination behaviour of grazing dairy cows. White *et al.* (2001) recorded the distribution of urinations of 36 grazing dairy cows (stocking rate of 2.48 cows/ha), in mid-lactation, during five 24 h periods. This study reported on the effects of water troughs and time spent in a location on the frequency of urination and distribution of urine. Higher than average deposits of urine around the water trough were reported and White *et al.* (2001) concluded that this was mainly due to warm weather causing increased drinking frequency. Concentrations of excreta events within 30 meters of the water trough were significantly greater in the warm months of the year than concentrations in the cooler seasons. White *et al.* (2001) also stated that the number of excretions that occur in a location is highly correlated to the time spent in that location. They found most urination events occurred in the paddock (84.1% urine) with no urination on the races (lane ways).

Oudshoorn *et al.* (2008) studied the spatial distribution of urination events of 60 lactating dairy cows grouped in three grazing treatments (4, 6.5 and 9 h at pasture). Each group was allocated a paddock of 1.5 ha. Urination events for each group were recorded during two 24 h periods using a hand-held GPS navigator. Urination frequency, for all treatments, was on average 0.26 per hour per cow in the paddock, with cows not observed to urinate on the races. Urination events were uniformly distributed in the field without specific hot-spots. No correlation was found between where cows urinated and lay down, however, cows were at pasture for a limited time (as defined by treatments) which may have influenced the time spent lying down.

A more recent study examined the effects of restricted grazing on the location of urination events in intensively managed dairy cows (Clark *et al.,* 2010). Forty-eight dairy cows in early lactation were allocated to three treatments (2 x 4 h, 8 h and 24 h grazing) in 833m^2 neighbouring plots. Urinations were recorded over 48 h, using urine sensors (AgResearch and Enertol Ltd.), in two separate weeks of the experiment. The study found that the proportion of urination events located on pasture and races was reduced by a third when grazing was restricted to eight hours per day. This resulted in capturing 35% to 38% of total urinations when cows are kept on a stand-off pad when not grazing and this could represents a substantial economic gain if the captured effluent is used as a fertilizer on the farm. Spatial distribution within the paddock was not examined.

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. 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.

Understanding the distribution of urine may allow the development of management practices that target 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 heterogeneous urine distribution.

The objectives of this study were to:

1. Quantify the temporal and spatial urination behaviour of dairy cows on a commercial farm;
2. Investigate potential relationships between urination density and physical properties of the grazed paddocks, climate and herd management.

2.2. Materials and Methods

Trials, each lasting eight days, were scheduled for March 2008, November 2008, January 2009 and March 2009. The trial in March 2008 had to be cancelled due to drought because cows were receiving large quantities of supplements with minimal access to pasture. This setting would not have represented a typical situation for a rotational grazing system. The rest of the trials were carried out as planned, however, equipment failure hindered retrieving reliable data in the November 2008 and January 2009 trials. Data from March

2009 were deemed complete and reliable, and have been used as the basis for this study. Detailed trial schedules, together with equipment description and outcome of experiments have been outlined in Table A1, Appendix I.

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 supplements were fed during the trial. Weather data for the duration of the study were obtained from the weather station based at the farm (Figure 2.1). The average times of sunrise and sunset were 07:15 h and 19:45 h respectively.

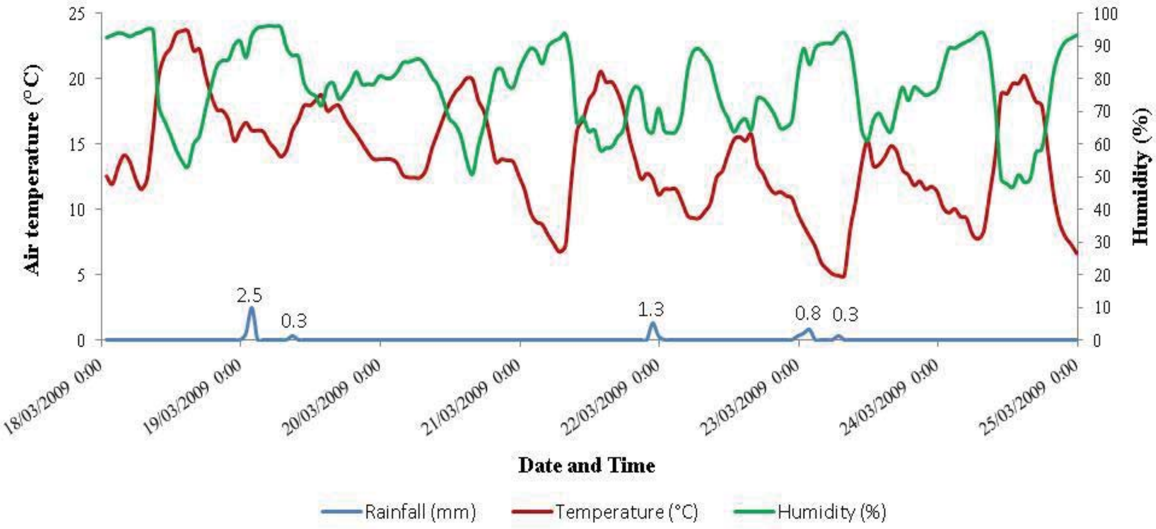


Figure 2.1. Climatic data for the days of observation.

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 (DairyNZ, 2004), and stocking rate of 180 cows/ha. Cows were milked twice a day in a rotary dairy system. The milking process involved the entire herd being removed together from pasture by a person on a four-wheel motorbike and being herded along the farm tracks to the milking shed. The herd were 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 the designated pasture. Cows received a fresh allocation of approximately 1.2 ha (standard deviation (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).

2.2.1. Animal Measurements

Thirty cows were selected from the herd based on age and milking order. 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).

Milking order

Each cow in the herd was identified with an electronic identification tag worn around the neck. When each cow stepped onto the milking turntable, her tag was scanned and information registered on a computer. This information was used primarily as a means of recording milk yields. However, this system also enabled the collection of information on the order in which cows entered the milking facility.

The herd was milked twice daily at around 05:20 h (AM) and 14:20 h (PM) in a rotary dairy. Electronic recordings of every milking for seven days prior to the observation period were obtained from the farm, giving a total of 14 separate milkings (7 morning milkings and 7 afternoon milkings). The identification of the cow and her position in the milking order (1, 2, 3 ... etc) were recorded. If a cow was not identified correctly by the scanner, the observer entered the cow’s identification number manually into the recording system.

The milking order consistency was examined by investigating the relationship between the milking orders of any two milkings using a traditional Pearson correlation (Botheras, 2006). Correlations between a range of different milkings for the duration of the seven days prior to observations were considered, as detailed bellow:

- Morning and afternoon milkings on the same day (AM - PM) (Table 2.1)
- Afternoon and subsequent morning milkings (PM - AM) (Table 2.1)

Table 2.1. Summary of correlation coefficients between milking orders of morning and afternoon milkings on the same day and afternoon and subsequent morning milkings.

Range of milkings	No. of correlations	Range of *r*[†]
AM – PM	7	0.222 – 0.456
PM – AM	6	0.196 – 0.529

[†] *r* = correlation coefficient

The herd was divided into three groups based on entry onto the milking platform. Cows that consistently entered early in the milking order, cows that consistently entered in the middle of the milking order and cows that consistently entered late in the milking order. For each of the 14 milkings that the milking order was observed, cows entering in the last 5% of the milking order were rejected. Excluding the last 5% of the order should have eliminated any sick or lame animals (Gadbury, 1975; Hassall *et a.*, 1993; Sauter-Louis *et al.*, 2004; Botheras, 2006). Selected animals were further balanced for age to proportionally represent the herd structure for each group of cows in the milking order (Table 2.2). A total of 30 cows were selected from the herd to be used in the trial, based on their age and position in the milking order.

Table 2.2. Age composition of the herd and study animals selected to represent the herd age structure.

Age (years)	Total number of cows (n=180)	% of total	Number of study cows (n=30)
2	40	22.2	7
3	55	30.6	9
4	32	17.8	5
5	18	10.0	3
6	10	5.6	2
7	9	5.0	2
8	8	4.4	1
9	4	2.2	1
10	1	0.6	0
11	2	1.1	0
12	1	0.6	0

GPS collars

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 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. The collar was 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 (Plate 2.1).

The GPS units were programmed to run continuously (sampling rate of 1 location fix per minute) 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 patch area, improved the accuracy of predicting animal location.

The GPS unit recorded date and time (GMT), latitude, longitude, HDOP and the number of satellites. The GPS coordinates were converted to New Zealand Map Grid coordinates using GIS software and a GIS layer of GPS locations was generated.

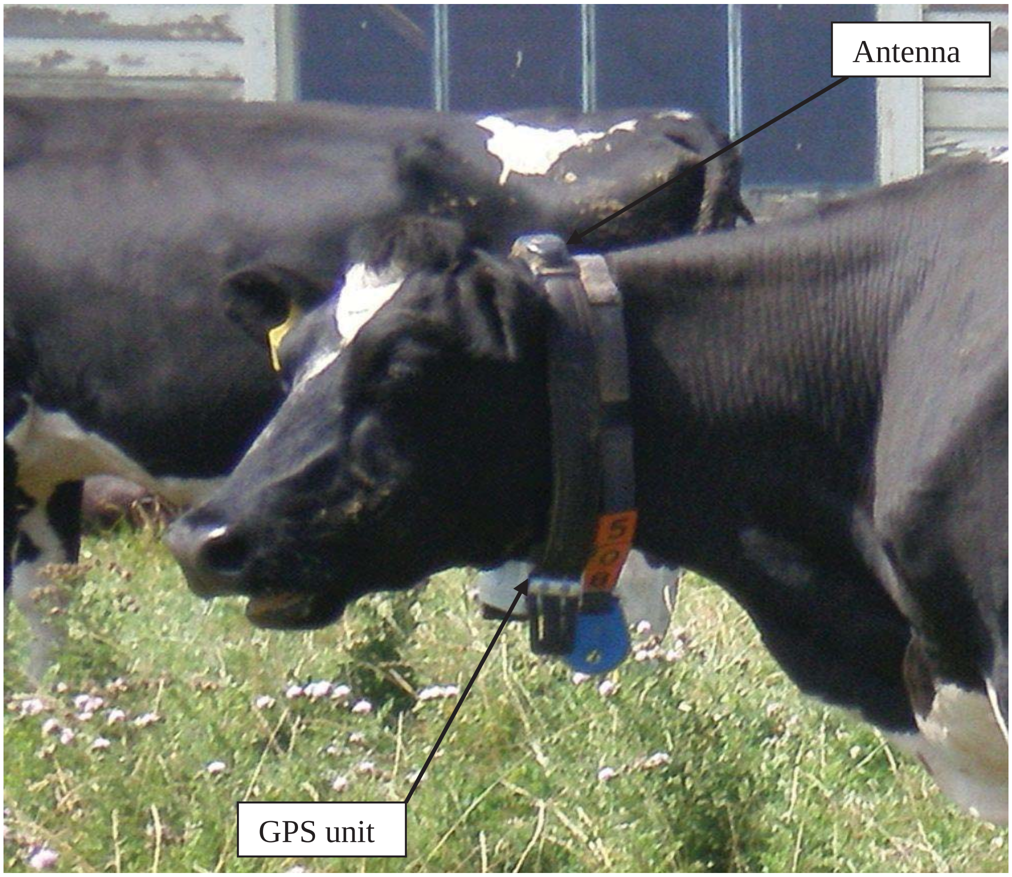


Plate 2.1. GPS collar with a GPS unit and antenna.

To evaluate the static or absolute error of the GPS units, 18 units were placed on fence posts at Dairy No. 4, Massey University away from shelter belts and farm buildings prior to the study. The units were programmed to run continuously for 70 hours. Throughout this period the weather remained fine, with no rain or extensive cloud cover. The position of a unit was assumed to be the centre point of all data for that unit. Error was computed as the distance from a data point to the centre point of a unit (Turner *et al.*, 2000) (Figure 2.2).

During the static test the units were immobile, therefore all measured distances are ‘perceived travel’. In total 52,039 readings were logged with a mean perceived movement of 2.1m, standard deviation of points of 1.2m and a range from 0.0 to 15.2m.

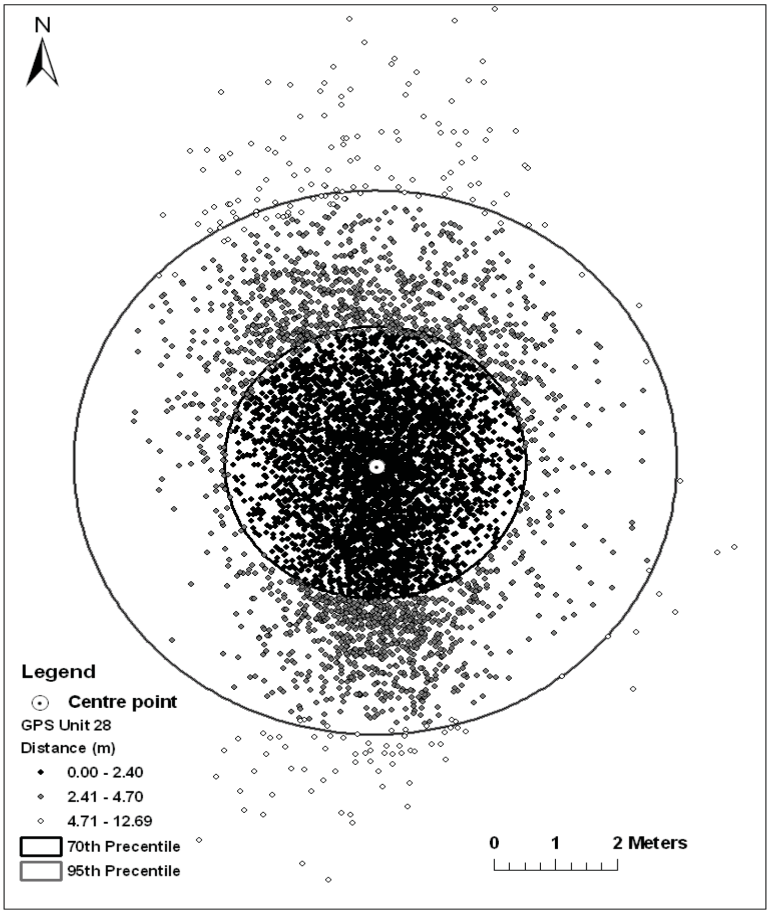


Figure 2.2. Static GPS test showing points, without differential correction, for one unit. 52,039 readings were recorded over 70 hours of continuous use. The inner circle encloses 70% of readings and has a radius of 2.4m, the outer circle encloses 95% of readings and has a radius of 4.7m.

Post-differential correction (DGPS) of data was not performed as it was deemed unnecessary due to the relatively small errors recorded during static testing compared to findings of other studies that have applied DGPS correction (see Moen *et al.*, 1997; Rempel and Rogers, 1997).

Urine sensors

Twenty four of the 30 cows, balanced for milking order and age to represent the structure of the herd, were also fitted with urine sensors for the duration of the study (AgResearch and Enertol Ltd.) (Plate 2.2). 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 (Plate 2.3). 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) where urine sensors were tested on sheep and beef cattle. Of the 29 beef cow urinations observed, all but one matched urination events detected by the urine sensors. However, the observer failed to see eight of the 27 urination events that were detected by the sensors. Although further work will provide more conclusive results, Betteridge *et al.* (2010b) concluded that it was unlikely that false-positive urinations events were created by the sensors. Observer fatigue or cows being out of line of sight during an urination event may be factors contributing to the high observation failure rate.

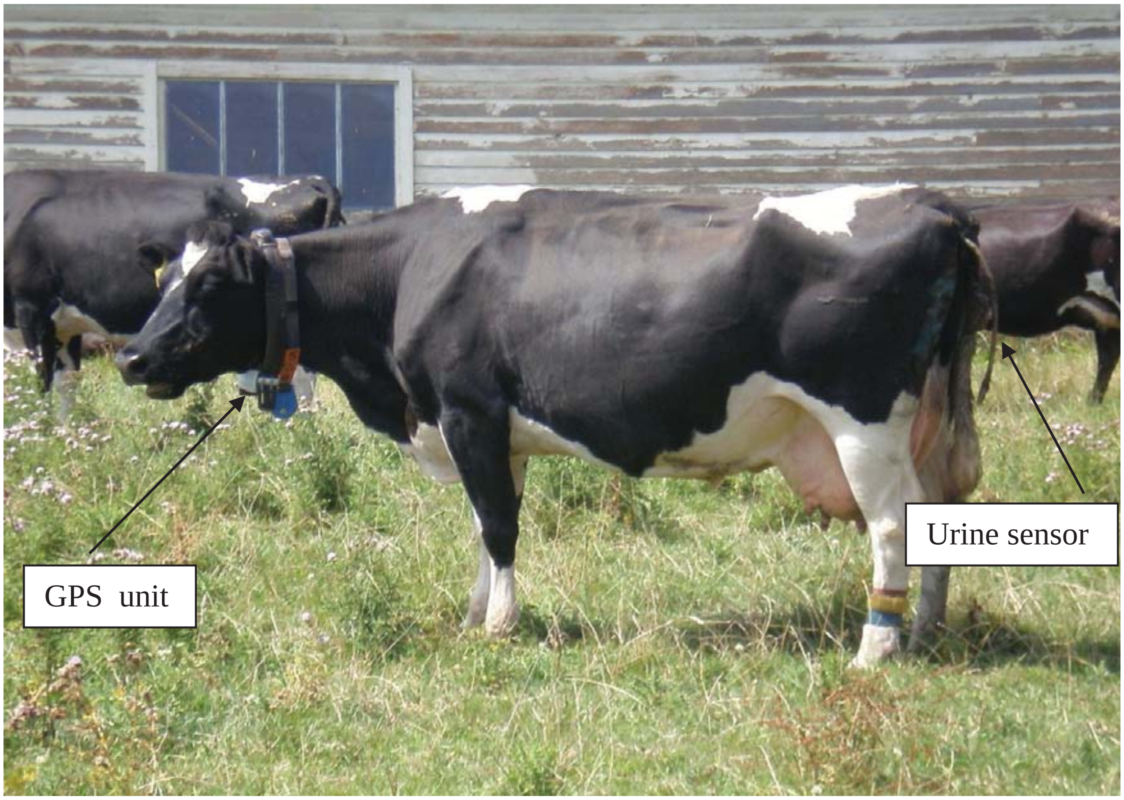


Plate 2.2. A dairy cow fitted with a GPS collar and a urine sensor.

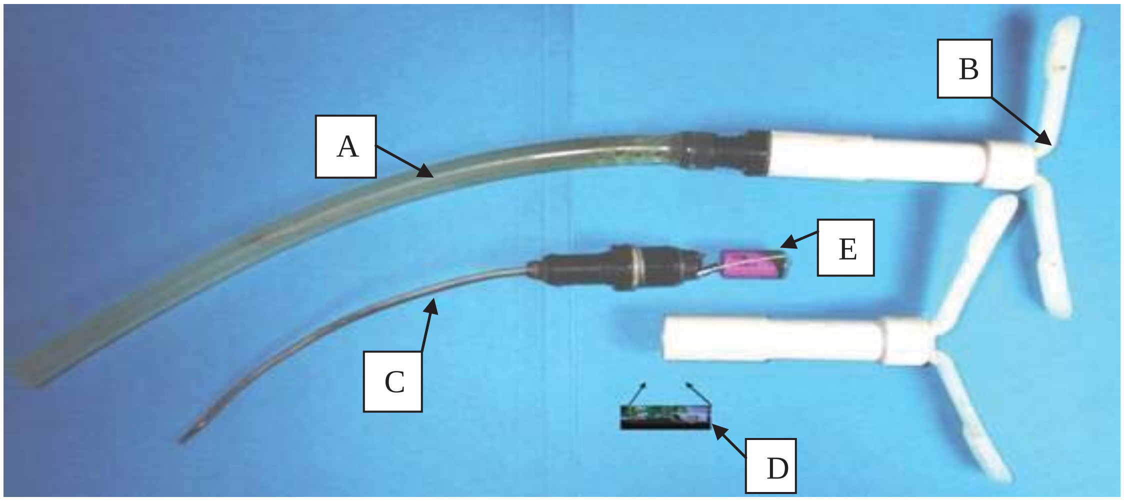


Plate 2.3. Cattle urine sensor: A, silicon tube with perforations; B, modified CIDR®; C, cable with thermistor at terminal end; D, electronic circuit board; E, N-type battery (After Betteridge *et al.*, 2010b).

2.2.2. Paddock Measurements

Pasture mass

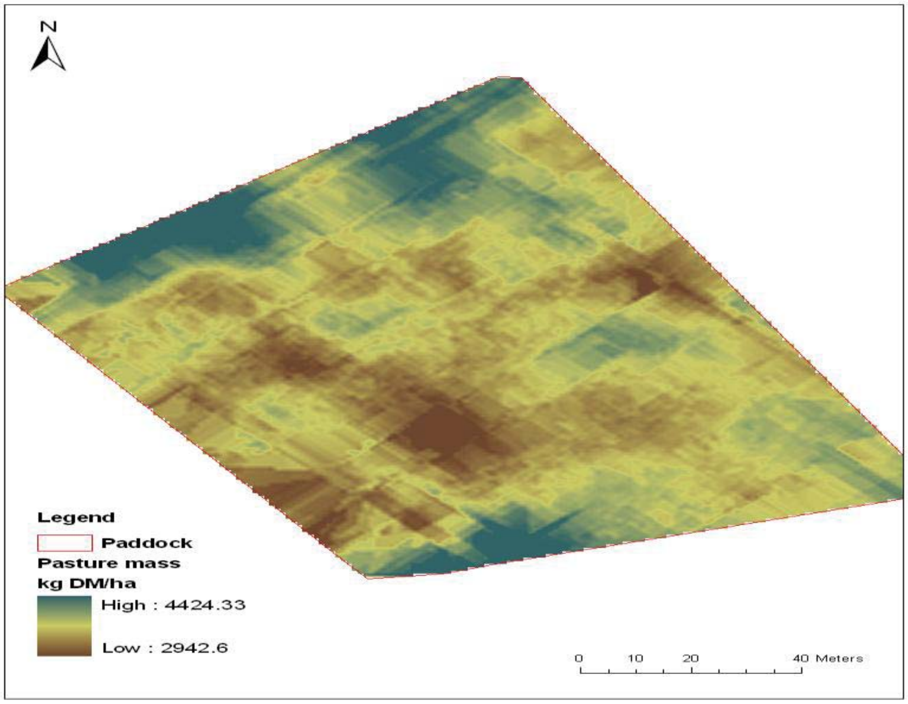
Pasture mass was measured prior to each grazing using the C-Dax Rapid Pasture Meter® (RPM). The RPM is pulled behind an All Terrain Vehicle (ATV) and can be used at speeds of up to 20 kmh^{-1} (Lawrence *et al.,* 2007). The ATV was driven across each paddock along parallel, regularly spaced tracks. A GPS has been incorporated with the RPM providing information on the position of collected readings in space and time. The RPM measures pasture height at approximately 200Hz, these 200 measurements per second are averaged to provide one data point. A speed sensor detects the forward speed of the device and if the ATV stops then the recording also stops. The height measurements (± 300mm) were converted into DM measurement (kg DM/ha) using calibration equations developed by Lawrence *et al.* (2007).

The RPM sensor output was used to create GIS layers of pasture mass (P_{mass}, kg DM/ha) for each paddock in the study (Table 2.3). Data output were of varied quality due to technical problems where data were not logged. Only data for eight of the 12 paddocks was used for analysis. 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 (Figure 2.3 a & b) using a spherical model (Haining, 2003).

Table 2.3. Pasture mass (P_{mass}) and range for each paddock.

Paddock	Mean P_{mass} (kg DM/ha)	Range of P_{mass} (kg DM/ha)
17a	3587	2904 – 4270
17b	3383	2744 – 4022
29a	3424	2794 – 4057
29b	3324	2791 – 3856
60	3665	3220 – 4110
61	3561	3223 – 3899
62	3683	2942 – 4424
78	3655	3068 – 4241

a)



b)

Figure 2.3. Representation of a) Rapid Pasture Meter® (RPM) track across a paddock and b) a pasture mass GIS layer generated following kriging from pasture height measurements.

Slope, Elevation, Aspect

A pre-existing digital elevation model (DEM), developed via an RTK survey (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 (Table 2.4). A map of the study area based on an aerial view of Dairy No.4 has been presented in Appendix I (Plate A1).

Table 2.4. Physical characteristics of each paddock.

Paddock ID number	AM/PM[†] grazing	Range of slope (degrees)	Range of elevation (m)	Range of aspect (degrees)
6	AM	0.27 – 19.08	67.47 – 70.08	247.5 – 337.5
7a	AM	0.15 – 32.38	63.91 – 69.50	202.5 – 360
7b	PM	0.06 – 31.05	62.96 – 68.22	202.5 – 360
17a	AM	0.14 – 28.83	70.91 – 76.33	112.5 – 360
17b	PM	0.50 – 4.27	71.67 – 74.95	247.5 – 337.5
29a	AM	0.06 – 37.73	42.27 – 50.78	157.5 – 295.5
29b	PM	0.47 – 39.45	45.67 – 55.67	112.5 – 202.5
60	PM	0.05 – 22.08	46.78 – 59.93	292.5 – 360
61	AM	1.02 – 12.74	49.09 – 54.89	247.5 – 360
62	PM	0.02 – 11.15	49.11 – 57.21	202.5 – 360
78	PM	0.53 – 30.67	41.33 – 52.06	112.5 – 292.5
79	AM	1.05 – 39.45	40.13 – 56.49	157.5 – 360

[†] AM: pasture used for grazing between morning and afternoon milkings; PM: pasture used for grazing between afternoon and morning milkings.

Gates and water troughs

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.

2.2.3. Statistical Analysis

Urination events

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.*, 2010). 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, New Zealand). 'Intensity' is the average density of points (number of points per unit area) and it is the first step in the analysis of the point pattern (Baddeley, 2008). Intensity may be consistent (homogeneous) or may vary from location to location (inhomogeneous). For example, if the point process X is homogeneous, then for any sub-region B of two-dimensional space, the expected number of points in B is proportional to the area of B and the constant of proportionality is the intensity. Intensity (i.e. density) units are numbers per unit area and generally the intensity of a point process is likely to vary from place to place. In some situations there could be singular concentrations of intensity (concentration of urinations in a stock camp). If it is suspected that the intensity may be inhomogeneous, the intensity measure can be estimated by a technique such as kernel density estimation, also referred to as kernel smoothing (KS), which is a technique used to assess first order properties of a point pattern (R 2.10.1 for Windows, R Development Core Team, New Zealand).

Kernel smoothing is a non-parametric way of estimating 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 some kernel and h is a smoothing parameter called the bandwidth. Quite often 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 x 5m for each paddock with a bandwidth of 25. Bandwidth was selected visually (Krisp *et al.*, 2009).

The second order analysis of 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. Complete spatial randomness 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. In K-S CSR real-value functions $T(x, y)$ are defined at all locations (x, y) (e.g. urine patch) in the observed area and then the function is evaluated at each of the data points $\{x\}$. The empirical distribution of values of T are then compared with the predicted distributions of values of T under CSR, using the classical Kolmogorov-Smirnov test to establish whether the data conform to a uniform Poisson process.

GPS data

Global positioning system point data were used to investigate the spatial preference of animals for locations within each paddock. Global positioning system 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, KS and K-S-CSR were used to investigate GPS point density and spatial distribution. One GPS unit failed to record location coordinates and data from it were unusable. 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 x 5m for each paddock with a bandwidth of 25. Bandwidth was selected visually (Krisp *et al.,* 2009).

A raster was created for each paddock following a 5m x 5m grid cell using ArcGIS 9 (ArcMap Version 9.3, USA). Each layer within the raster represented a factor (e.g. slope, urination density, distance to water trough). A density value was calculated for each factor per cell per paddock using kernel density estimation with R 2.10.1 for Windows (R Development Core Team, New Zealand). 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. Data were based on the density estimates of each factor in corresponding cells in each paddock.

2.3 Results

Urination behaviour

The mean number of daily urinations events for cows was 9.8 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 urinations were recorded during PM grazing (55.5%

in 14 h) than AM grazing (44.5% in 8 h) out of the total urination events on pasture ($P < 0.05$). More urination events were recorded on 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 2.4). 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, $P = 0.5$).

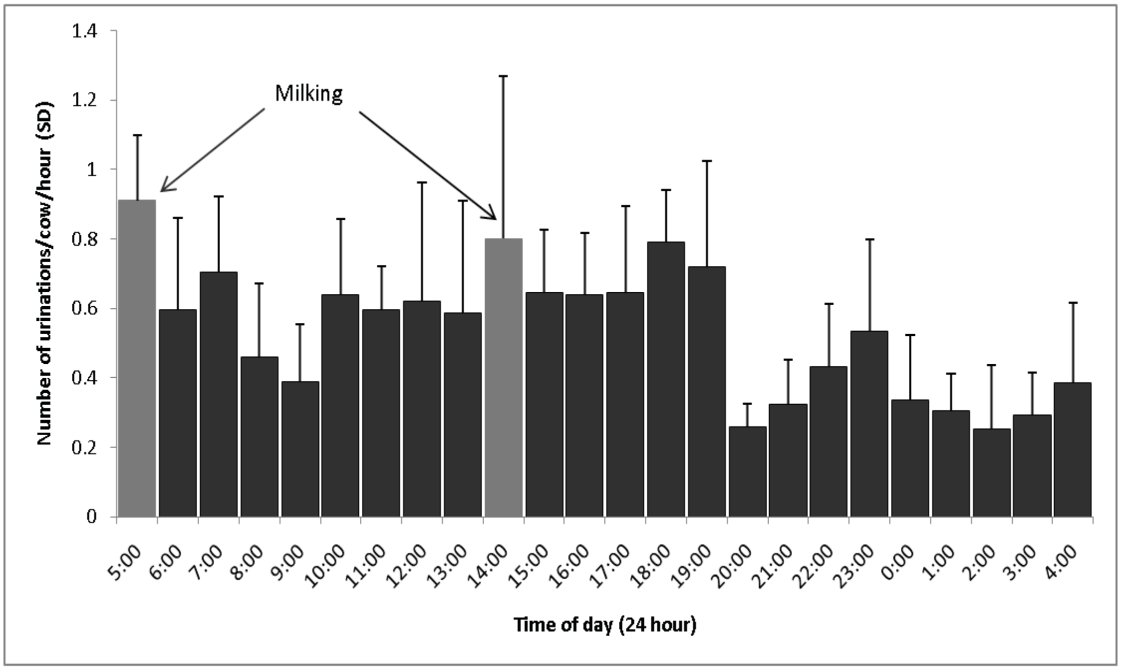


Figure 2.4. Temporal distribution of urination events of 15 cows over seven consecutive days.

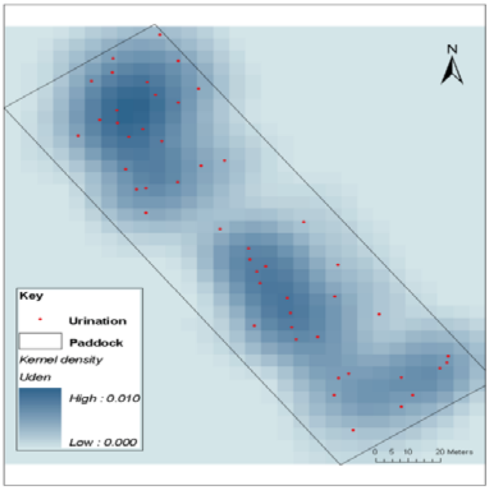
Urination density and distribution

Kernel density estimation indicated a non-homogeneous intensity of urination events within all paddocks (Figure 2.5). 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 2.6c, d, e, f, h, k).

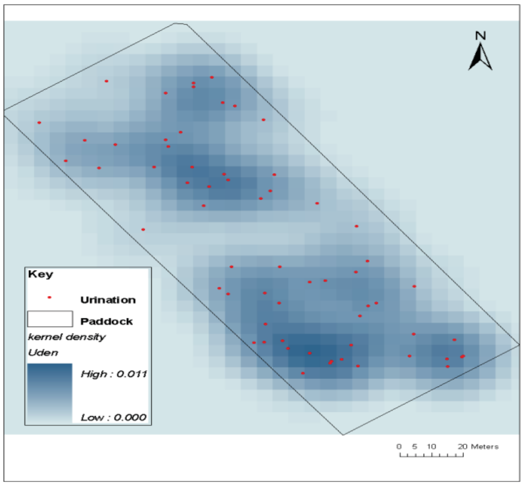
Relationships between urine density (U_{den}) and environmental factors

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} observed in eight individual paddocks (Table 2.5). 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_{den} 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*.

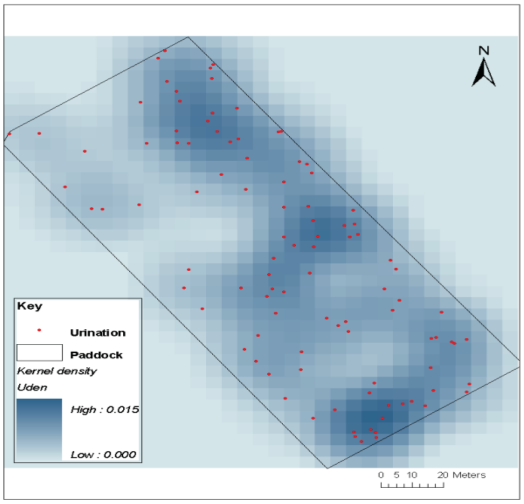
Distance to paddock gates (G_{dis}) was positively correlated with U_{den}, while distance to water troughs (W_{dis}) was found to be negatively related to U_{den} on the whole (Table 2.6). There was variation in the type of correlation between G_{dis} and U_{den} amongst paddocks. In five of the paddocks 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} (Figure 2.7). In contrast, in six paddocks W_{dis} was significantly negatively related to U_{den}, while a positive correlation was found in only one paddock.



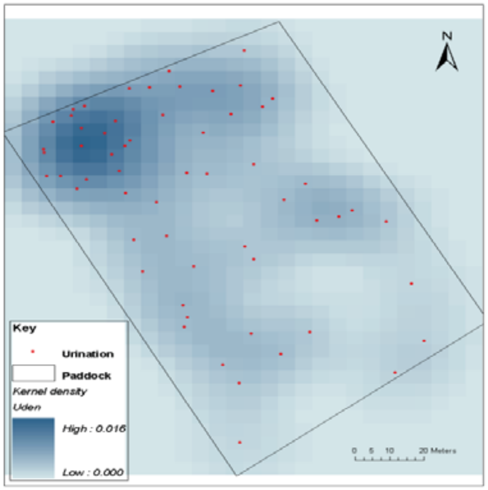
a) Paddock 6



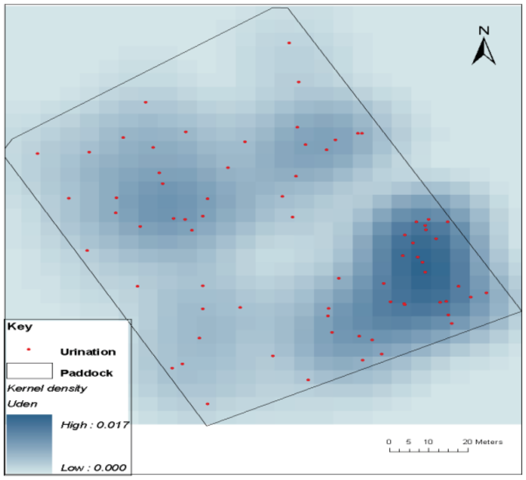
b) Paddock 7a



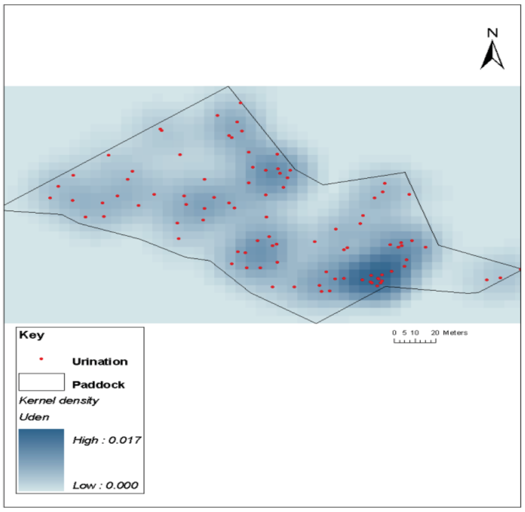
c) Paddock 7b



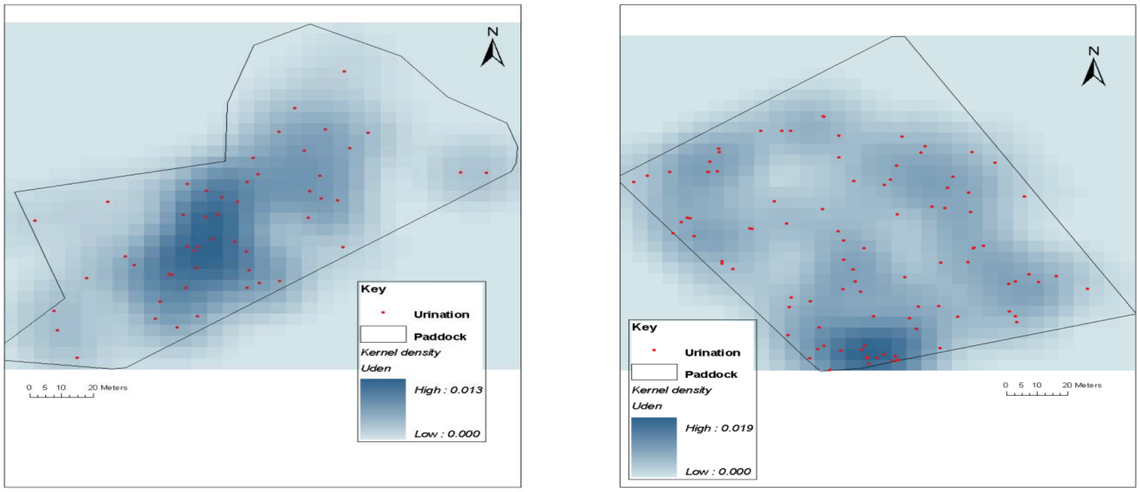
d) Paddock 17a



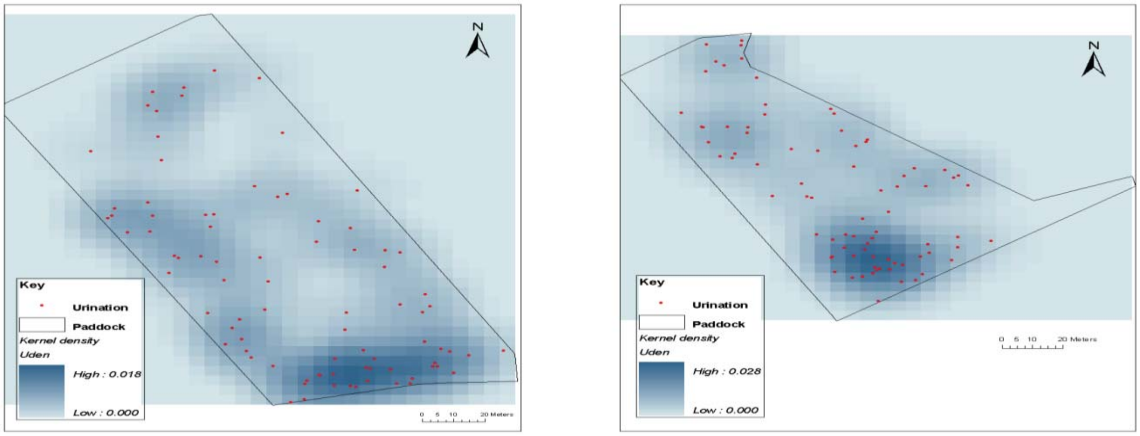
e) Paddock 17b



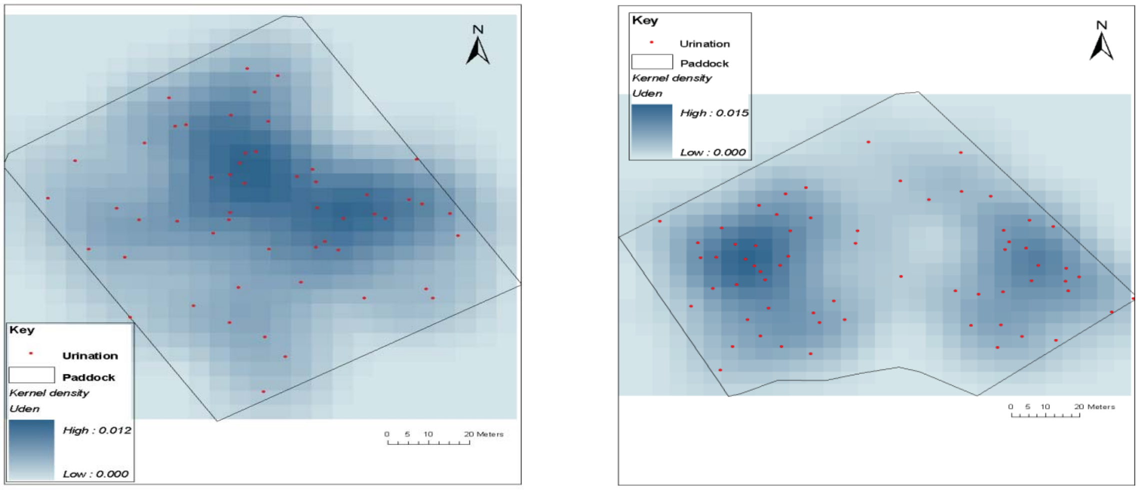
f) Paddock 29a



g) Paddock 29b j) Paddock 62

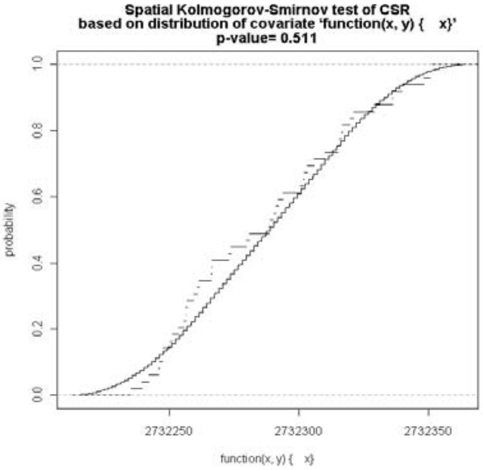


h) Paddock 60 k) Paddock 78

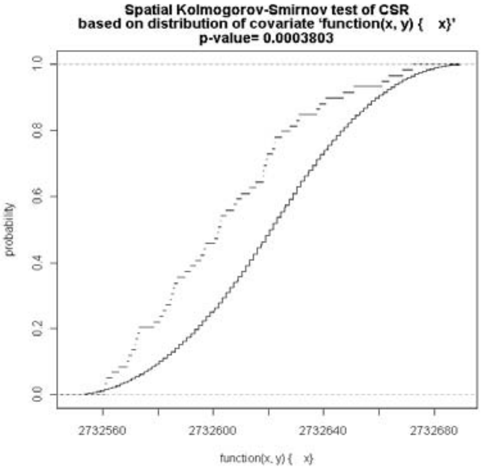


i) Paddock 61 l) Paddock 79

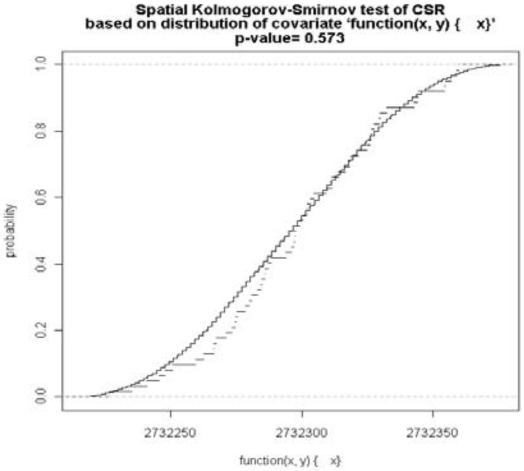
Figure 2.5. Kernel density estimates of urination based on a 5m x 5m cell grid for each paddock. Actual urination events have been superimposed.



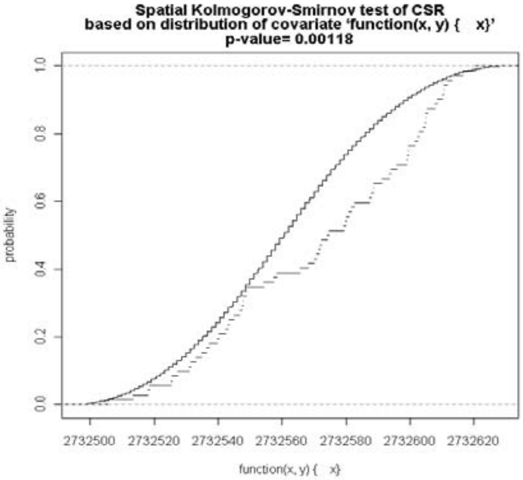
a) Paddock 6



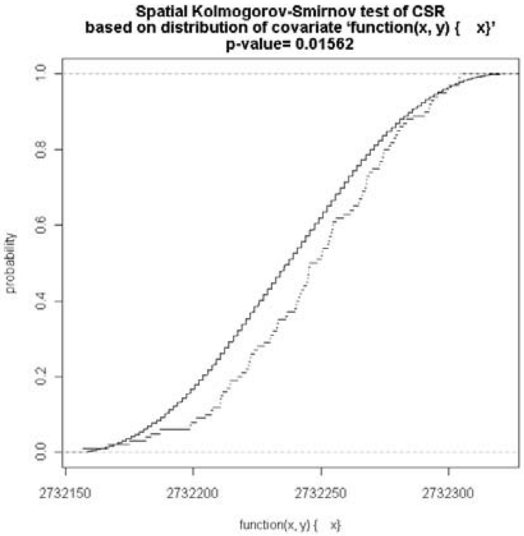
d) Paddock 17a



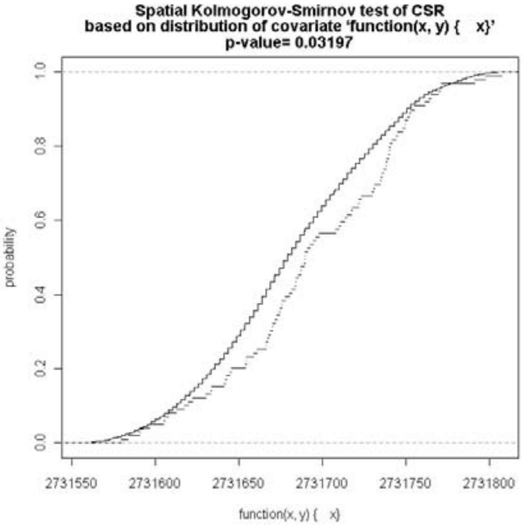
b) Paddock 7a



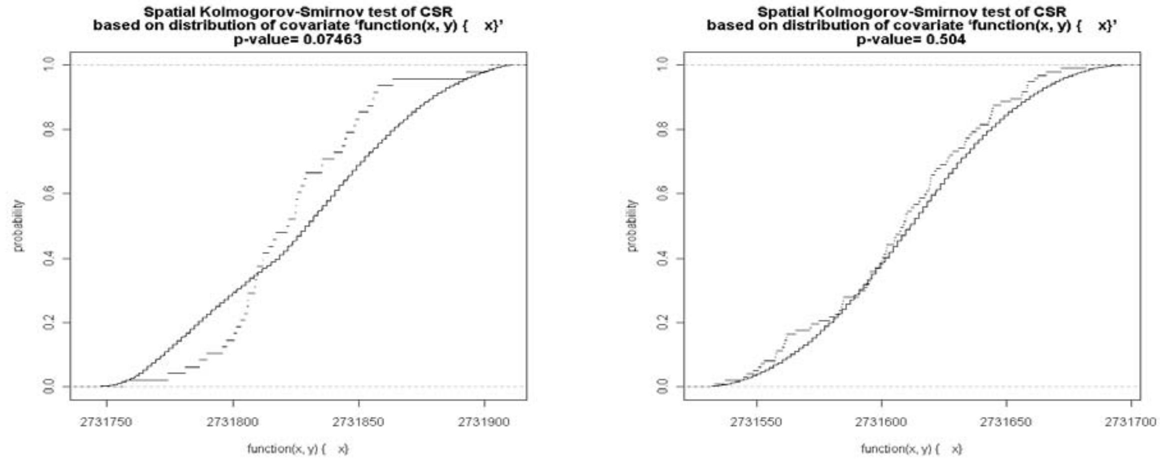
e) Paddock 17b



c) Paddock 7b

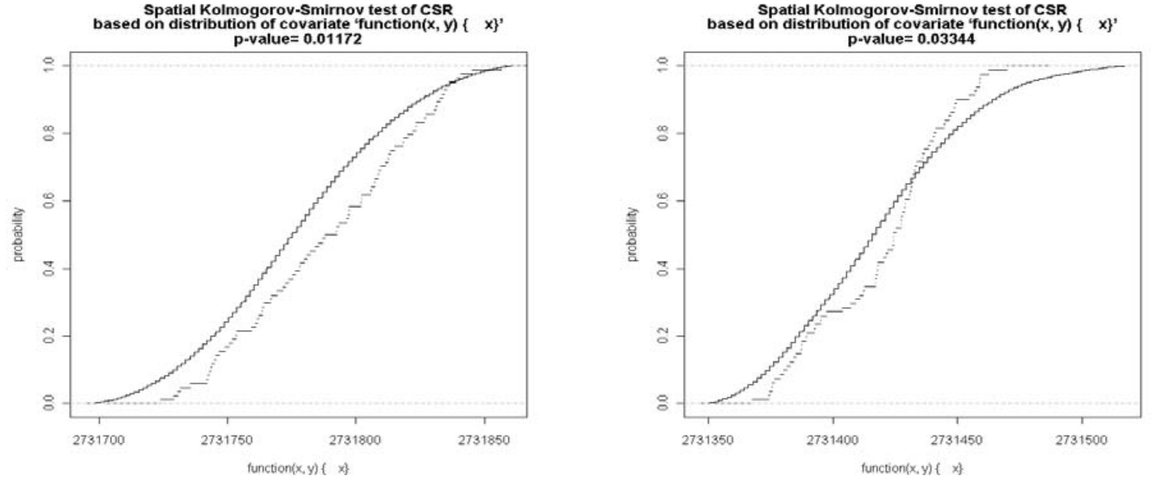


f) Paddock 29a



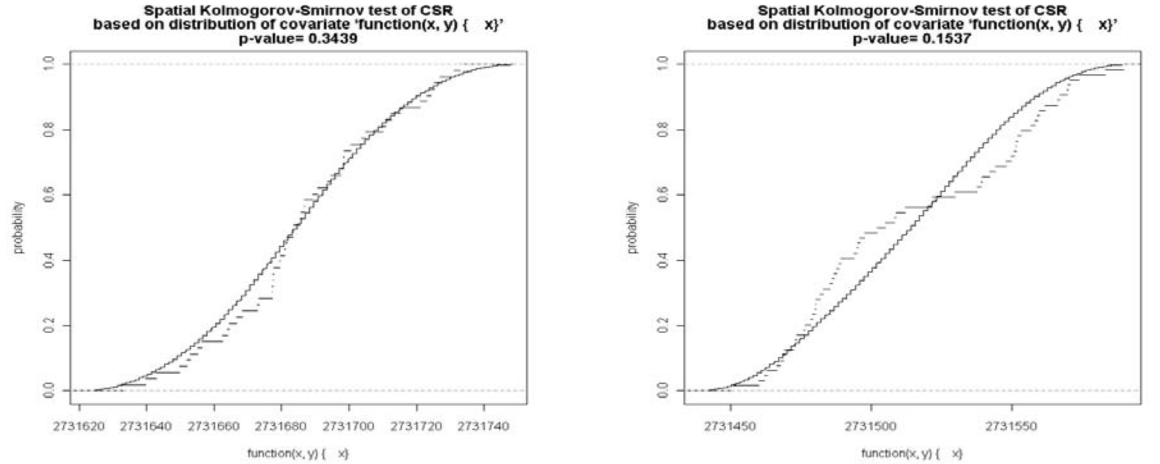
g) Paddock 29b

j) Paddock 62



h) Paddock 60

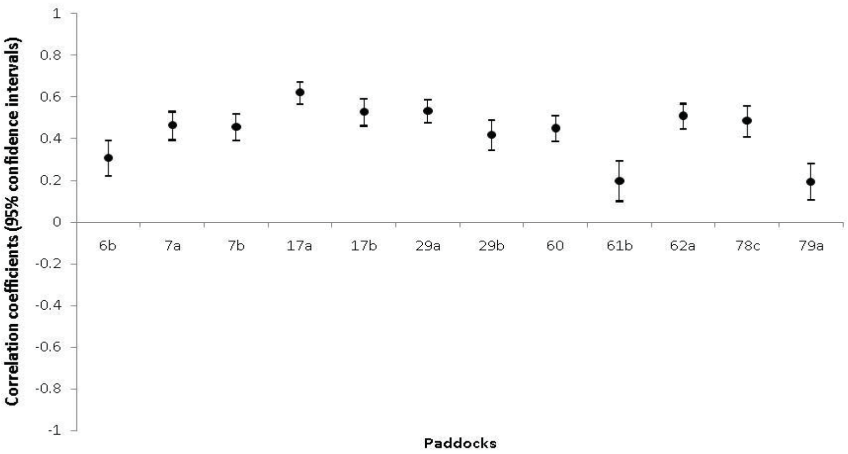
k) Paddock 78



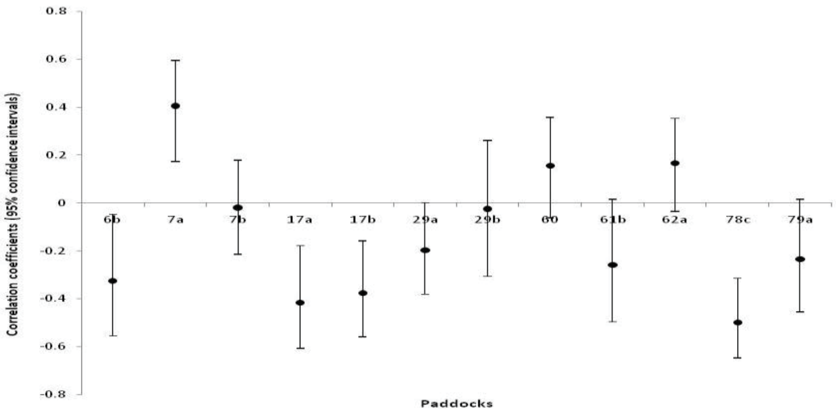
i) Paddock 61

l) Paddock 79

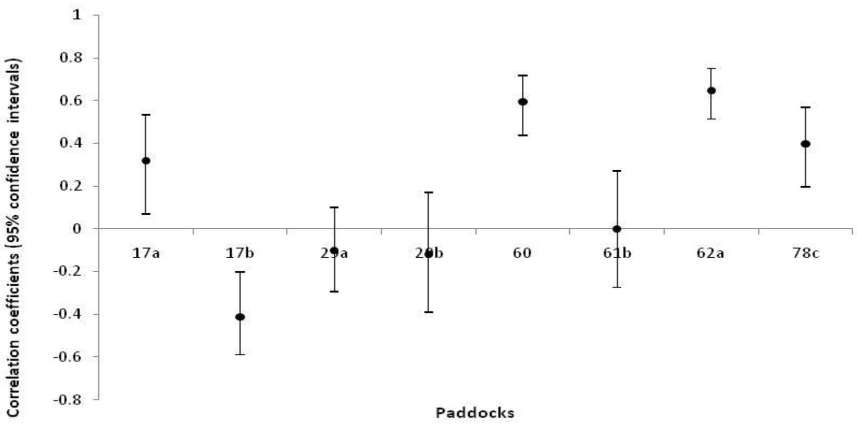
Figure 2.6. Results from Kolmogorov-Smirnov test for Complete Spatial Randomness of urinations for each paddock. Deviations of the observed data distribution from the normal curve (predicted distribution) indicate aggregation of urine within particular areas of the paddock.



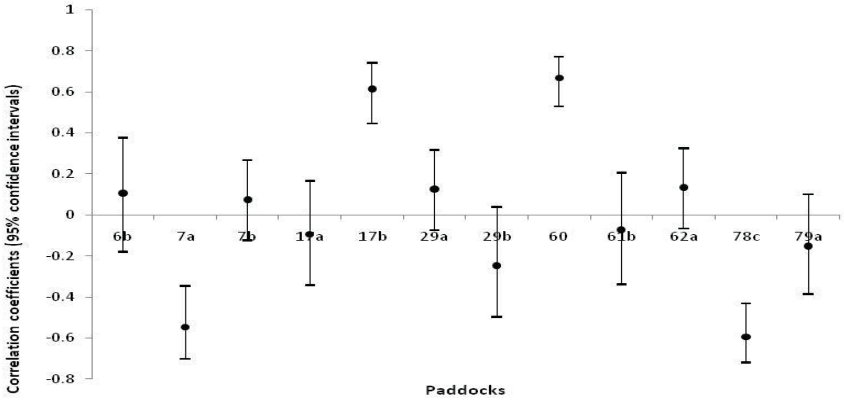
a) T_{den}



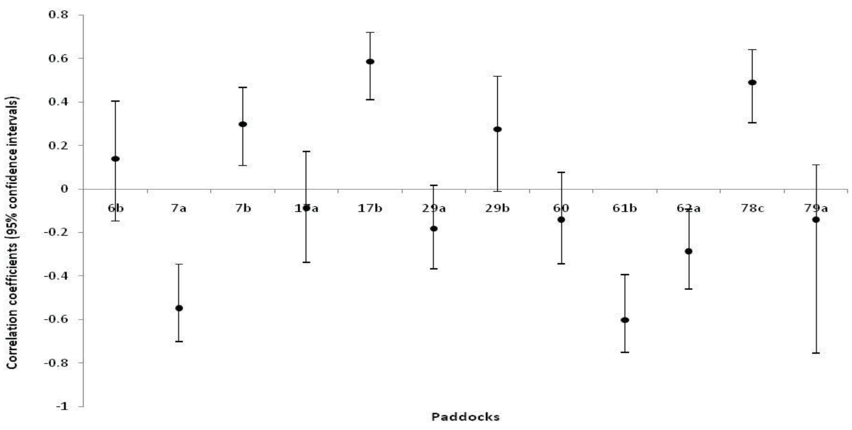
b) *Slope*



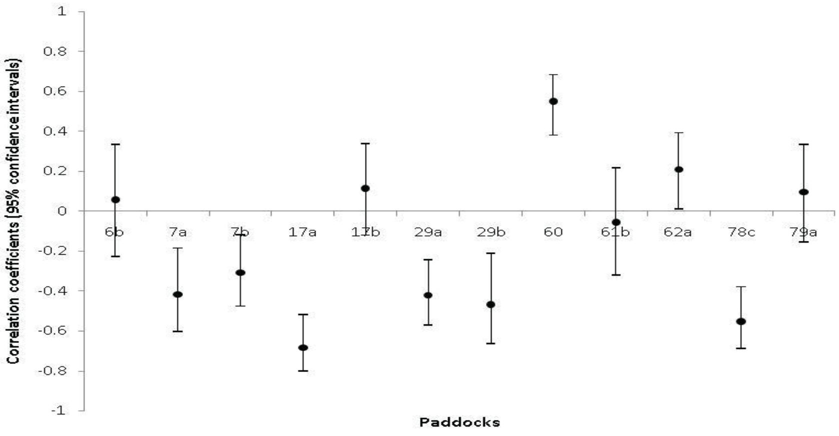
c) P_{mass}



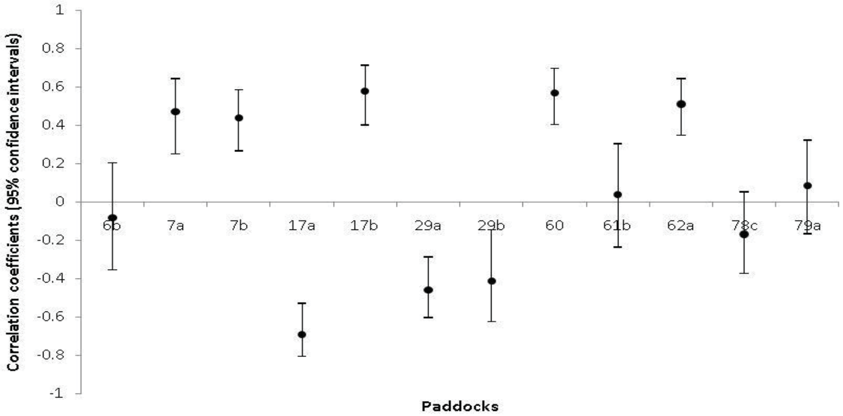
d) *Elevation*



e) Aspect



g) W_{dis}



f) G_{dis}

Figure 2.7. Correlation coefficients of variables with U_{den} for each paddock. U_{den}: urine point density per 25m^2; T_{den}: GPS point density; P_{mass}: pasture mass (kg DM/ha); G_{dis}: distance (m) to paddock gates: W_{dis}: distance (m) to water troughs.

Table 2.5. Correlation coefficients and their significance amongst variables.

	U_{den}	T_{den}	*Slope*	P_{mass}	*Elevation*
T_{den}	0.485 ***				
Slope	-0.061 NS	-0.074 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 NS	-0.151 ***	-0.194 ***	0.028 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 2.6. 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.

2.4 Discussion

The mean number of daily urination events (9.8 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. 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 and by Betteridge *et al.* (2007) for sheep. 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 highly affected by temperature.

The herd management system in this study meant that the majority of urinations by cows (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. 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, indicating that the present method used to gather data on urination behaviour of commercially managed dairy cows is reliable.

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), and similar results were also reported by Betteridge *et al.* (2010a) studying urination behaviour of sheep in a hill country environment. The period of low urination frequency (20:00 h to 04:00 h) is also the time when grazing frequency was low and lying behaviour increased (results will be discussed in detail in Chapter 3), comparable to findings by Gibb *et al.* (1998, 2002a) and Orr *et al.* (2001). Dairy cows exhibit distinctive patterns of urination and it appears that the frequency of urination is affected by temporal factors mainly during the PM grazing period, in particular there is a sudden decrease in urination activity at dusk. There is less variation in the frequency of urination between hours during the AM grazing, and milking times resulted in an increase in urination activity.

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 AM grazing. 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-stocked beef 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).

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). 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 overall. 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, 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.*, 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. 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 also 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 (Tucker *et al.*, 2007) 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 a 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 farmer, 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. Furthermore, management practices resulted in a steady stream of individuals through the gates, with cows not observed to congregate around gates prior to leaving the paddocks for milking. 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. Therefore, in this study warm weather should probably not be considered as a cause of increased urination density distribution near water troughs in relevant paddocks. Seasonal studies may shed more light on likely causes.

2.5. Conclusions

1. Urine sensors and GPS units showed promise as a method for capturing data on the temporal and spatial urination behaviour of a dairy cow herd. There was some indication that urine deposition may be non-random indicating that there was an aggregation of urine patches within grazed paddocks.
2. The spatial density patterns of urine patches indicate that there is an association between urination and the time spent in a location, however 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. Behaviours like grazing and resting have been associated with urine distribution and environmental factors in several studies in sheep (Betteridge *et al.,* 2007, 2010a) and in indoor dairy systems (Arland *et al.*, 2002). Associations between activity patterns, urination density and distribution and environmental factors will be discussed in the next chapter.

Chapter Three: Investigation into the relationship between activity patterns, environmental factors and urination behaviour of dairy cows

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3.1. Introduction

Most animal species have distinct activity patterns (Lenthoed, 1977) and for the dairy cow some of the more common behaviours performed include grazing, ruminating and maintaining social structure with co-specifics (Phillips, 1993). Factors such as topography, pasture mass, available shade and/or shelter can all affect distribution of nutrients through the effect of these on the behaviour of individual animals or groups. A paddock having a wide range of these characteristics is likely to be utilised in a variety of ways by livestock (Phillips, 1993; Kendall *et al.*, 2006; Tucker *et al.*, 2007; Betteridge *et al.,* 2010a). For example, it is probable that areas of the paddock with greater pasture mass or lower slope gradient may lead livestock to spend longer in these areas than elsewhere, with the probability that nutrient distribution may be similarly biased. Moreover, livestock are likely to respond to these characteristics in different ways between seasons (Hessle *et al.*, 2007)..

Preliminary studies on farms with set-stock sheep and beef cattle indicate that soil nutrient concentrations are higher in areas where livestock congregate, such as in stock camps (Betteridge *et al.*, 2007). The negative environmental impact due to animal excreta being concentrated in stock camps can be of concern where they are close to streams and wetlands (McDowell and Srinivasan, 2009). Losses of N 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 (Pleasants *et al.*, 2007; Shorten and Pleasants, 2007) and ammonia (NH_3) volatilisation (Di and Cameron, 2003).

Studies in the 1950s have provided detailed descriptions of how small groups of dairy cows kept on pasture allocate time to different behaviours over a 24-hour period (Castle *et al.*, 1950; Hardison *et al.*, 1956). Both studies looked at the behaviour of four lactating dairy cows grazing pasture of different qualities over several 24-hour periods in a two month trial. The total time in a 24-hour period each cow spent grazing, ruminating, lying, loafing (included the time spent walking, standing and being milked), and the number of defecations and urinations per cow were recorded. These studies also tried to identify possible factors that might influence the behaviour of dairy cows (such as pasture quality and lactation stage) and examined individual variations within groups.

Castle *et al.* (1950) studied the behaviour of dairy cows over four observation periods and found large individual variations (260 to 629 min/24 h) in the time spent grazing. The average time spent grazing was lowest (296 min/24 h) when the cows grazed a poor quality pasture late in the grazing season. Grazing activity peaked in the morning, immediately after morning milking, followed by a steady decline in the number of cows grazing until afternoon milking. There was a similar peak in grazing activity following the afternoon milking with a continual decline with end of grazing by 2200 h. Grazing after this time was sporadic. Most of the rumination behaviour was carried out when the cows were lying down (81%), however the time spent lying down by individual cows varied from 366 min/24 h to 689 min/24 h. The majority of time spent lying down was at night and again after the morning grazing period. Time spent loafing (defined as the time spent not grazing or lying down, which included the time spent standing or walking and either doing nothing or ruminating, and the time spent being milked) took up 496 min/24 h while time spent milking accounted for 210 min/24 h of the total. The number of urinations (7 to 15/24 h) and defecations (5 to 15/24 h) per cow also showed individual variation in a 24-hour period.

Hardison *et al*. (1956) also found individual variation during the time spent grazing which was significant both within and between study periods. Time spent ruminating showed some individual differences (480 to 501 min/24 h) among cows, with lying down time mainly occurring during the hours of darkness and immediately following the first grazing period after morning milking. The average time spent loafing was 358 min/24 h of which 225 min/24 h were spent in the milking shed. The individual variation in the number of urinations (6 to 14/24 h) and defecations (11 to 17/24 h) was similar to the observations made by Castle *et al.* (1950).

Other studies, such as those of Phillips and Leaver (1986) and Phillips and Hecheimi (1989) also provide quite detailed time budget information, although some behaviours like drinking, eliminating and grooming were not investigated. The study by Rind and Phillips (1999) which examined the effect of group size on ingestive and social behaviour of dairy cows on pasture, provides one of the more recent and detailed accounts of the behaviour of dairy cows. The study examined the time spent grazing, ruminating, standing and lying, together with providing information on the incidents of aggression, self grooming and allogrooming.

More recent studies describing detailed behaviour of dairy cows are rarer, as studies are mostly carried out to investigate particular factors and so only specific aspects of behaviour related to these factors are studied. For example, Orr e*t al.* (2001) studied the effect of grass supply on the grazing patterns of four groups of five dairy cows, over 10 weeks, kept under different grazing allocation regimes. The study aimed to improve both production and pasture utilisation, therefore only time spent grazing was recorded. Phillips and Rind (2002), on the other hand, investigated the effects of social dominance on production and behaviour of 66 grazing dairy cows. For this study, only the social and grazing behaviours of dairy cows were recorded. Oudshoorn *et al.* (2008) studied the spatial distribution of urine of 60 lactating dairy cows grouped in three grazing treatments (4, 6.5 and 9 h at pasture). Each group was allocated a paddock of 1.5 ha, of which 0.5 ha was used as a buffer area. Observed urination events of each group were recorded during two 24 h periods. Urinations were uniformly distributed in the field without specific hot-spots. No relationship between urine and lying down distributions was found.

Early and more recent studies provide description of how small groups of lactating dairy cows kept on pasture allocate their time to different behavioural activities over different periods of time. One study by Botheras (2006) investigated the behaviour and welfare of grazing dairy cows in Victoria (Australia) under commercial conditions. Twenty Friesian cows, in a herd of 180, were observed over two consecutive two-week periods in peak and again in mid-lactation. Records of the grazing, ruminating, lying, standing, eliminating and social behaviour were made.

There was no literature found that investigated both temporal and spatial patterns of behaviour and paddock utilisation of dairy cows managed under typical commercial conditions. This study aimed to provide base line knowledge of how dairy cows utilize paddocks and distribute urine in regard to several environmental factors with particular emphasis on the relationship between urine distribution and the grazing, lying, standing and walking behaviours of dairy cows. An understanding of the spatial distribution of urine by grazing dairy cows will give a better indication of where N losses are most likely to occur and create a potential for new management solutions.

The objectives of this study were to:

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

3.2. Materials and Methods

The study took place on a commercial dairy farm in Massey University, Palmerston North, New Zealand during early autumn in March 2009. The composition and herd management details have been presented in Chapter Two, Section 2.2.

3.2.1. Animal Measurements

Thirty cows were selected from the herd based on position in the herd at milking (i.e. milking order) and age, the same study group as in Chapter 2. A detailed explanation of the methods used to select and manage cows in the study has been given in Chapter Two, Section 2.2. All animal experimentation was carried out following approval by the Massey University Animal Ethics Committee (Protocols 08/06 and 08/53).

Activity monitors

Seventeen cows, already fitted with GPS units and urine sensors and balanced for milking order and age to represent herd structure, were fitted with IceTag3D® activity monitors (Ice Robotics, Scotland) (Plate 3.1). The device is strapped to the cow's back leg just above the claw. Each unit weighs 190 g and it is contained in a plastic housing (96 x 81 x 31 mm). The IceTag3D® activity monitors use accelerometer technology to determine the proportion of time an animal is lying, standing or active (which total 100% for each time period). The device also generates a count of steps taken in a given period. Data are stored until downloaded and data can be exported in time periods of seconds, minutes, hours or weeks. Data were exported to an Excel spreadsheet using a one minute time period. The activity monitors are independent of the GPS unit and have their own power supply. IceTag3D® activity monitor validation is described by McGowan *et al.* (2007) and Trenel et al. (2009)..

Activity data generated by the IceTag3D® activity monitors do not distinguish between different active states such as grazing and walking. An algorithm was used to calculate the proportion of time spent grazing and walking from the activity data. This algorithm was developed by Aharoni *et al*. (2009) studying the grazing behaviour and energy costs of activity between different types of cattle, which partitioned grazing activity from walking based on the slower step rate of the grazing cow.

Plate 3.1. IceTag3D® activity monitor fitted to the back leg of a dairy cow (Source: Ice Robotics, Scotland, UK).

The approximate location of grazing, lying, standing or walking events was determined by matching the time of the recorded behaviour event with GPS time. The merged datasets were used to generate a GIS layer of grazing, lying, standing and walking locations in space and time.

GPS collars and Urine sensors

The thirty cows that were selected for the study were fitted with GPS units and 24 of these were also fitted with urine sensors. A detailed description of equipment and explanation of procedures associated with the GPS collars and urine sensors has been given in Chapter Two, Section 2.2.

3.2.2. Paddock Measurements

Pasture mass, the slope, elevation and aspect for each paddock, together with positions of paddock gates and water troughs were recorded using the same techniques described in Chapter Two, Section 2.2.

3.2.3. Statistical Analysis

Activity data

Activity monitors provided data from 17 cows. Behaviour frequency, based on the mean proportion of time spent in each behavioural variable (grazing, lying, standing and walking) 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 the cows' identification number. Pearson correlation coefficient was used to examine the relationships between each behavioural variable and age, and milking order position (Minitab Inc., State College, Pennsylvania).

Behaviour point density and distribution were investigated using ArcGIS 9 (ArcMap Version 9.3, USA) and R 2.10.1 for Windows (R Development Core Team, New Zealand). 'Intensity' is the average density of points (number of points per unit area) and it is the first step in analysis of a point pattern (Baddeley, 2008). Intensity may be consistent (homogeneous) or may vary from location to location (heterogeneous). For example, if the point intensity *X* is homogeneous, then for any sub-region *B* of two-dimensional space, the expected number of points in *B* is proportional to the area of *B* and the constant of proportionality is the intensity. Intensity units are numbers per unit area and generally the intensity of a point process is likely to vary from place to place. In some situations there could be singular concentrations of intensity (concentration of cows lying in particular location). If it is suspected that the intensity may be inhomogeneous, the intensity measure can be estimated by a technique such as kernel density estimation also referred to as KS (R Development Core Team, New Zealand). Kernel smoothing is a non-parametric way of estimating 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 some kernel and *h* is a smoothing parameter called the bandwidth. Quite often *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*:

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

Behaviour point density (behaviour 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). A 'lag' factor of +2 min was applied to lying behaviour data per hour, when kernel smoothing images were made, in order to incorporate urine deposits that normally follow long periods of lying (Phillips, 1998; Betteridge K., personal communication).

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. In K-S CSR real-value functions *T(x, y)* are defined at all locations *(x, y)* (e.g. urine patch) in the observed area and then the function is evaluated at each of the data points $\{ x\}$. The empirical distribution of values of *T* are then compared with the predicted distributions of values of *T* under CSR, using the classical Kolmogorov-Smirnov test to establish whether the data conforms to a uniform Poisson process.

Urination events

Data provided by the urine sensor were handled and analgised in the same way as described in Chapter Two, Section 2.2.

A raster was created for each paddock following a 5m x 5m grid cell using ArcGIS 9 (ArcMap Version 9.3, USA). Each layer within the raster represented a factor (e.g. slope, urination density, distance to water trough). A density value was calculated for each factor per cell per paddock using kernel density estimation with R 2.10.1 for Windows (R Development Core Team, New Zealand). Pearson correlation coefficient was used to examine the relationships between urination and behaviour point density, slope, elevation, aspect, pasture cover and the locations of water troughs and paddock gates. Data were based on the density estimates of each factor in corresponding cells in each paddock.

3.3. Results

Activity patterns

Cows spent on average 40% (SD 8.6) of their time grazing, 38% (SD 9.6) lying, 15% (SD 7.5) standing and 7% (SD 2.0) walking in a 24 h period. No significant variation between animals was found in the mean percentage of time each spent standing, grazing, lying or walking ($P = 0.5$ for all variables) over 24 hours. However, there was a significant positive correlation between the age of the cow and the time spent standing and a negative correlation with grazing and walking, with older cows spending more time standing and less time grazing or walking than younger cows. Milking order was unrelated to behaviour activity (Table 3.1).

Table 3.1. Correlation coefficients and their significance amongst behavioural variables and animal factors.

Behaviour	**Age**	**Milking order**
Grazing	-0.80	-0.16
	***	NS
Lying	0.21	0.00
	NS	NS
Standing	0.65	0.23
	**	NS
Walking	-0.59	-0.49
	*	NS

***: P < 0.001; **: P < 0.01; *: P< 0.05; NS: not significant.

Time of day had a significant effect on the frequency of grazing, lying, standing and walking ($P < 0.001$ for all variables). A table of means and standard deviations for each behavioural variable per hour is presented in Appendix 2 (Table A2). Grazing activity decreased after 19:00 h and increased again after 04:00 h (Figure 3.1). There were two peak grazing periods from 06:00 to 08:00 h and 15:00 to 20:00 h, and two smaller peak grazing periods at around 10:00 h and 23:00 h. Cows spent the majority of their time lying between 20:00 and 04:00 h. Standing behaviour occurred throughout the 24 h, with peak times at

05:00 and 14:00 h. Walking activity increased prior to the cows being taken for milking at 04:00 and 13:00 h. The majority of lying and standing activity (75% and 60% respectively) was recorded during PM grazings, while 46% of all grazing behaviour was observed during AM grazings. During PM grazings 74% of the time spent grazing for the period was recorded between 15:00 and 20:00 h. These activity patterns were constant within each of the paddocks with no significant differences in the frequencies of different behaviours between paddocks (*P* = 0.5 for all variables).

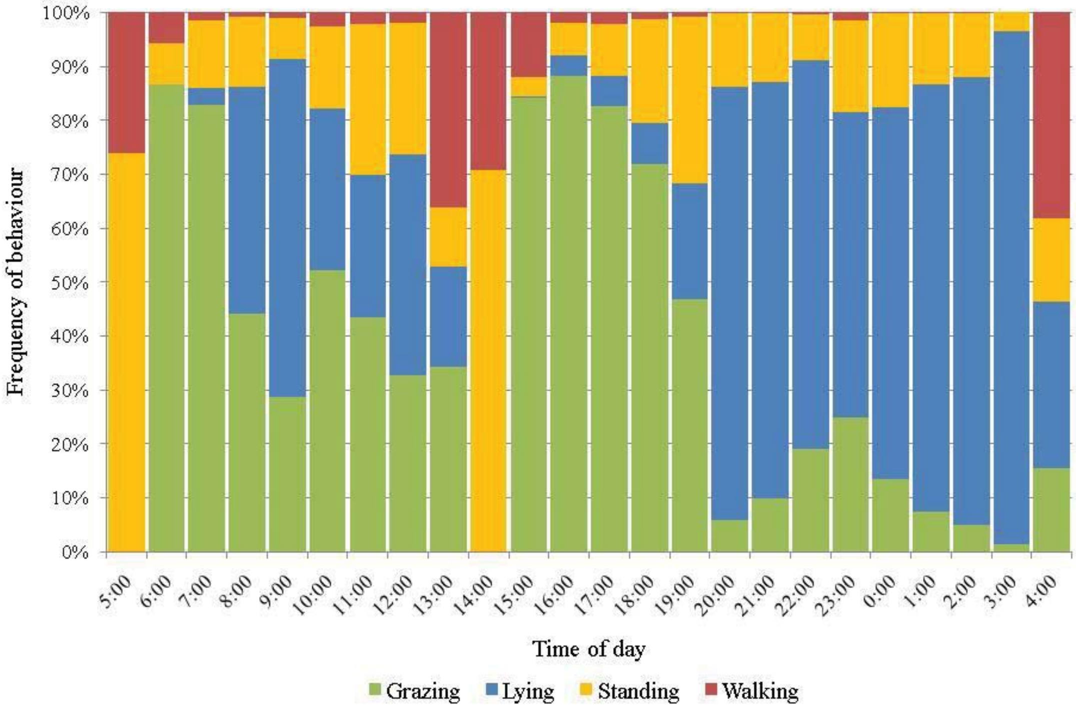


Figure 3.1. Temporal patterns of grazing, lying, standing and walking behaviour for 17 cows over seven consecutive days. Data based on the mean % of time spent per cow per hour in each behavioural variable.

Activity patterns and urination frequency

The frequency of urination increased with the increase in grazing frequency, while there was a negative relationship between frequencies of urination and lying behaviour (Table

3.2). Standing behaviour had a weaker association with urination frequency whereas walking was unrelated to frequency of urination.

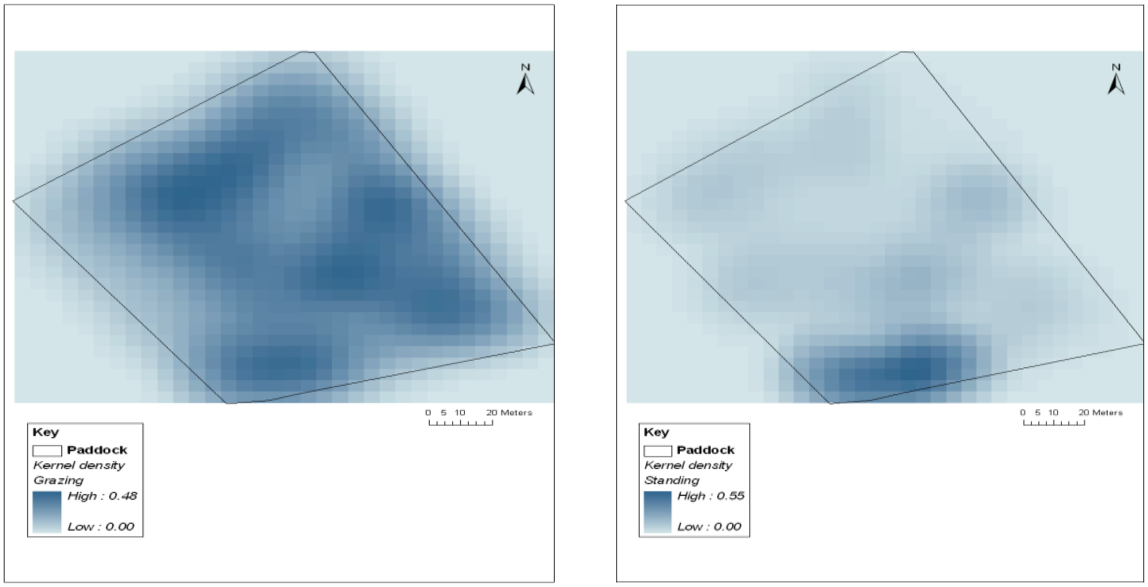
Table 3.2. Correlation coefficients and their significance amongst the frequency of behavioural variables and the frequency of urination.

Behaviour	$r^{\dagger}$	***P*-value**
Grazing	0.57	<0.0001
Lying	-0.66	<0.0001
Standing	0.37	<0.0001
Walking	0.03	0.735

† r = Correlation coefficient.

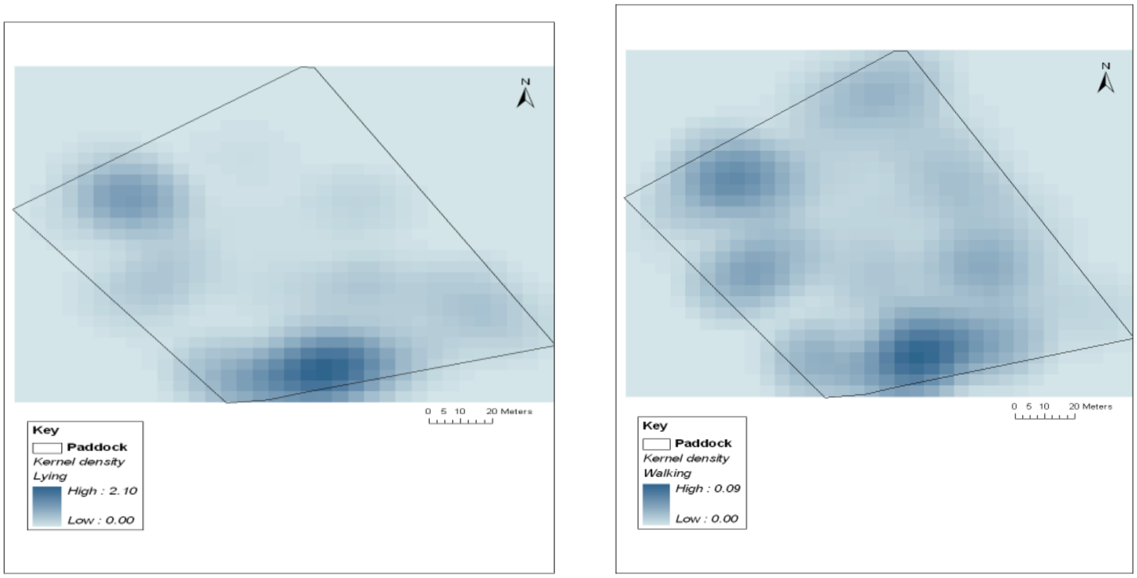
Density and distribution of grazing, lying, standing and walking behaviour

Kernel density estimation indicated a non-homogeneous intensity for all behaviour variables within all paddocks (examples of kernel density maps for each behaviour variable per paddock are given in Figure 3.2. A complete set of maps is presented in Appendix 2). A non-random distribution is indicative of aggregation of animals performing a specific behaviour within particular areas of the paddocks. All paddocks were found to have a significant non-random distribution of grazing, lying, standing and walking behaviour. (Examples of Kolmogorov-Smirnov test for Complete Spatial Randomness for each behaviour variable per paddock are given in Figure 3.3. A complete set of maps is presented in Appendix 2).



a) Grazing

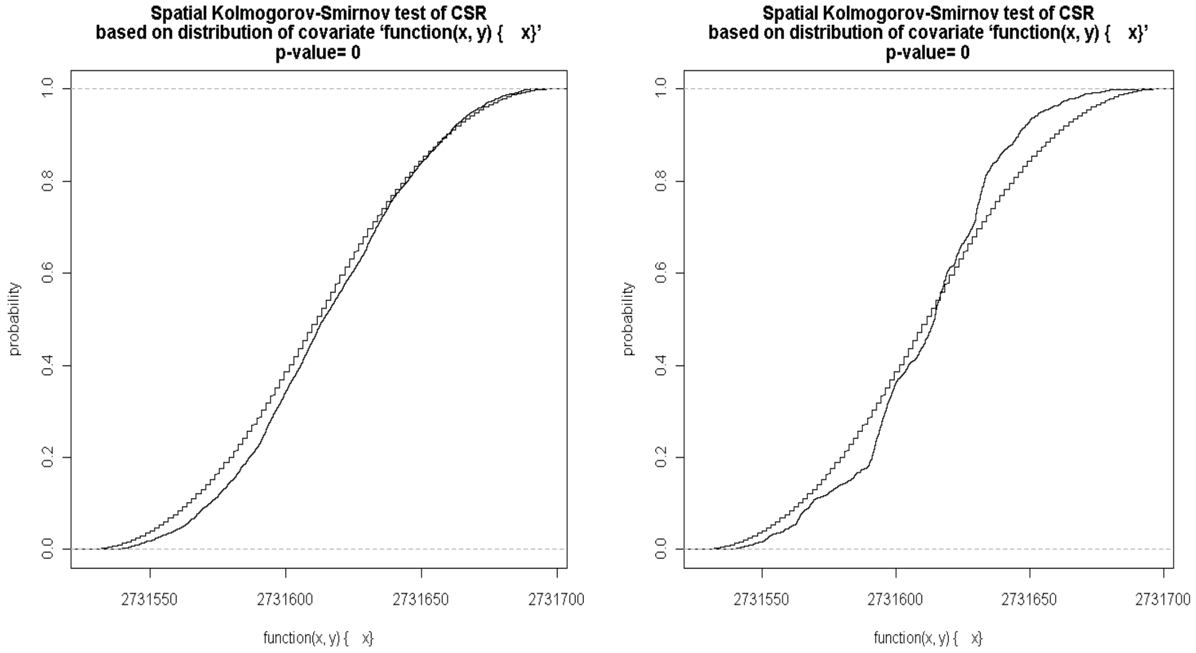
c) Standing



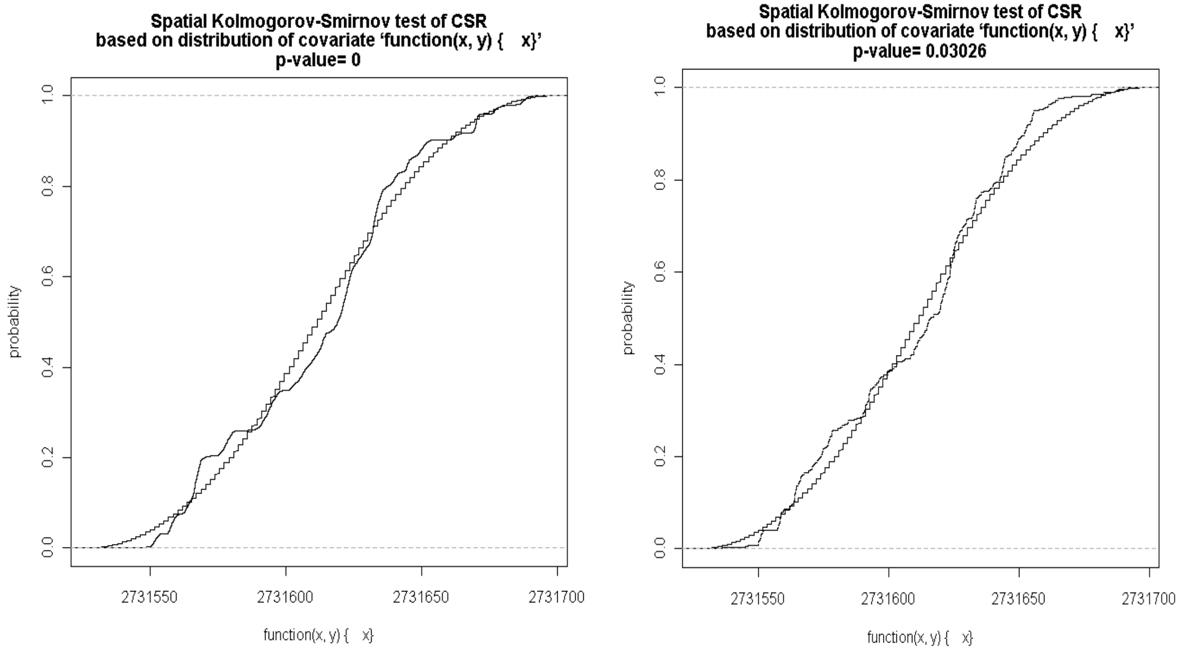
b) Lying

d) Walking

Figure 3. 2. Kernel density estimates of grazing, lying, standing and walking behaviour based on a 5m x 5m cell grid for paddock 62.



a) Grazing c) Standing



b) Lying d) Walking

Figure 3.3. Results from Kolmogorov-Smirnov test for Complete Spatial Randomness of grazing, lying, standing and walking behaviour for paddock 62. Deviations of the observed data distribution from the normal curve (predicted distribution) indicate aggregation of grazing within particular areas of the paddock.

Relationship between urine patch density and the density of behaviour variables

The densities of all behaviour variables were positively correlated with the density of urine patches, although the correlations were weak (Table 3.3). The relationship between urine patch density and lying and standing behaviour density was somewhat stronger than that with grazing and walking.

Table 3.3. Correlation coefficients and their significance amongst the density of behavioural variables and urine patch density (U_{den}) for the 12 study paddocks.

Behaviour	**No. of correlations**	**$r^{\dagger}$ (range of r)**	***P*-value**
Grazing	12	0.30 (0.13-0.62)	<0.0001
Lying	12	0.42 (-0.04-0.54)	<0.0001
Standing	12	0.43 (-0.13-0.68)	<0.0001
Walking	12	0.30 (-0.06-0.62)	<0.0001

† r = Correlation coefficient.

Relationship between density of behavioural variables and environmental factors

Although there were several significant relationships amongst variables in general, the correlations were very weak (Table 3.4). A figure of correlation coefficients for each behavioural variable and environmental factor per paddock is presented in Appendix 2. Relationships between behavioural variables and environmental factors varied from paddock to paddock, with no consistent trends being observed. For example, there was a weak negative relationship between *Aspect* and the density of standing behaviour overall. However, this was due to the effect of one paddock, where there was a moderate negative correlation between the two variables (r = -0.70).

Table 3.4. Correlation coefficients and their significance amongst behavioural variables and environmental factors.

Behaviour	***Aspect***	***Elevation***	***Slope***	P_{mass}	W_{dis}	G_{dis}
Grazing	0.00	0.10	-0.11	0.12	-0.02	-0.02
	N S	***	***	***	N S	N S
Lying	0.05	-0.05	-0.07	0.01	-0.08	-0.07
	N S	N S	N S	N S	N S	N S
Standing	-0.36	-0.06	-0.08	0.20	0.09	0.13
	***	N S	N S	***	N S	***
Walking	-0.03	0.01	-0.03	0.22	-0.09	-0.12
	N S	N S	N S	***	N S	***

***: $P < 0.001$; **: $P < 0.01$; *: $P < 0.05$; NS: not significant.
P_{mass}: pasture mass (kg DM/ha); W_{dis}: distance (m) to water troughs; G_{dis}: distance (m) to paddock gates.

3.4. Discussion

Extrapolating the behavioural results to an estimate of total time that cows spent performing specific behaviours suggests that in mid to late lactation, cows spent on average 9.6 h/day grazing, 9.1 h/day lying, 3.6 h/day standing and 1.7 h/day walking. These values compare quite well with results from other observations of dairy cows grazing pasture without supplementary feed (Table 3.5).

The estimated time spent grazing in this study was consistent with other studies (Table 3.5), with the exception of Wales *et al.* (1998) because that study was undertaken in Victoria, Australia during an autumn drought condition that was likely to have affected pasture characteristics (Dalley *et al.*, 2001). Therefore, time spent grazing in that trial might have been reduced due to reduced forage availability, while the time spent standing may have increased as cows were unable to graze.

Table 3.5. Results from the present study and other experiments describing the behaviour (h/d) of dairy cows in mid-late lactation grazing pastures without supplements.

	Grazing[a]	**Lying**	**Standing**	**Walking**
Present study	9.6	9.1	3.6	1.7
Botheras (2006)	8.8	9.1	N/A	N/A
Thorne *et al.* (2003)	9.5	8.9	N/A	N/A
Phillips and Rind (2002)	10.1	10.3	3.3	N/A
Wales *et al.* (1998)	7.5	10.0	6.5	N/A
Stockdale & King (1983)	10.0	N/A[b]	N/A	N/A

[a] Values are average
[b] N/A: not reported

These results were comparable with other studies suggesting that observation of the behaviour of the number of selected animals, managed as part of a commercial grazing dairy herd, in the present study reliably describe how cows allocate their time to major behavioural activities. Furthermore, estimates of the time cows allocate to behavioural activities when managed as part of a large commercial herd (present study) or in small pasture plots (other studies) appeared to be similar. The method and equipment used to monitor the behaviour of dairy cows in a commercial herd have provided reliable data, comparable to that of smaller studies. This provides evidence to support McGowan *et al.* (2007) contention that the IceTag3D® motion sensor data can be used to interpret behavioural activities, in place of human observers. Therefore, these data, when linked to GPS and other sensor data allows for the successful study of dairy cows under a commercial setting.

There was no significant variation between animals in the present study in all behaviour variables. This is in contrast to results by Phillips and Denne (1988) and Rook and Huckle (1996) where significant between-cow variation for the time spent grazing and ruminating was found. Botheras (2006), on the other hand, reported between-cow variation only in the time spent urinating and defecating for cows in mid-lactation.

Rook and Huckle (1995) have shown that the grazing and standing behaviour of cows in groups is synchronised rather than random. The simultaneous effect of environmental (e.g. weather, sunrise, sunset) and management (e.g. milking) cues on the behaviour of individual cows, along with the potential effect of social facilitation, often lead to behaviour synchronisation being observed in a group of grazing cattle. Therefore, there is a possibility that social facilitation of grazing and resting behaviours in large groups reduced the between-animal variation in the present study. This may explain why the results in this study are in contrast to findings by Phillips and Denne (1988) and Rook and Huckle (1996).

The age of the cows had an effect on the allocation of time spent grazing, resting and walking. With increase in age, cows were found to have reduced grazing and walking times, while the time spent standing increased. These results are in contrast to findings by Phillips and Leaver (1986) reporting no significant differences between adult cows and first lactation cows in grazing times. The latter study, however, compared only two groups of cows and did not investigate differences between all age classes.

In beef cattle, 3 year old cows have been found to graze for longer than 5 and 7 year old cows (Dunn *et al.*, 1988) and it was suggested that an increase in nutrient requirements per unit liveweight of young cattle may contribute to increased foraging time of younger cows. Bao *et al*. (1992) also found a significant negative correlation between total grazing time and the age of lactating Friesian dairy cows.

Gadbury (1975) and Botheras (2006) suggested that older cows were more likely to have problems with their feet and experience difficulty walking than younger cows, so this may explain the findings in the present study where walking time decreased while standing time increased with the age of the cow. The time spent lying in this study was not affected by the age of the cow, being similar to findings by Chaplin and Munksgaard (2001) and Krohn and Munksgaard (1993) studying dairy cows in tie-stalls. Differing results may also be due to differences between studies, such as pasture type and availability, breed of cow and the effects of dominance hierarchy on accessibility to resources at pasture.

There were four grazing periods, two major and two minor, in the behaviour of the dairy cows in the present study. Similar grazing patterns were reported by Hardison *et al.* (1956), Trotter and Lamb (2008) and Betteridge *et al.* (2010a). The latter two studies investigated the behaviour of beef cattle and reported peak grazing periods from 06:00 to 09:00 and 16:00 to 20:00 h. The grazing periods following morning and afternoon milkings were much more pronounced than grazing periods at 10:00 h and 23:00 h in this study, in accordance with O'Connell *et al.* (1989) and Rook *et al.* (1994). Gibb *et al.* (1998, 2002a) reported that the longest meal of the day was the grazing period immediately between afternoon milking and dusk. This is in agreement with findings in the present study where the longest grazing period was observed to take place between 15:00 and 20:00 h, with sunset at 19:45 h. One reason for this could be that DM and soluble carbohydrates accumulate in grass during the day (Rook, 2005). Therefore, Marotti *et al.*, (2002) noted that eating more grass in the afternoon when time can be spent ruminating during the night may be preferable to the animal and consistent with maximising fitness. Furthermore, cows may avoid grazing in darkness in order to minimise risk of predation (Kerbs and Davis, 1993), even if the risk of predation is only perceived. Gibb (2006) also observed an increase in night grazing during times when there was a full moon (i.e. light moon phase). Thus, the major factors influencing the beginning and ending of grazing in the dairy cow appeared to be the removal for milking and dusk, while night grazing is mainly affected by the moon phase.

The dairy cows in the present study were observed to have two major lying periods, between 08:00 and 10:00 h and from 20:00 to 05:00 h. Similar lying down periods, both after morning grazing period (Hardison *et al.*, 1956) and from sunset to sunrise (Hardison *et al.*, 1956; O'Connell *et al.*, 1986) were reported in other studies. Lying behaviour and rest are very important for dairy cows, and dairy cows are highly motivated to lie down (Munksgaard and Simonsen, 1996) as these activities are important for physiological and psychological restoration, and to prevent fatigue (Albright, 1993). In addition, O'Connell *et al.* (1989) found a high correlation between lying down and ruminating, with ruminating behaviour mostly observed throughout the night and interspersed with grazing during the day (Phillips, 1993; Gibb *et al.,* 2002). Rumination is an important process that enables cattle to digest coarse grasses (Phillips, 1993).

Standing and walking behaviours were observed less often, with standing predominantly occurring during the time of milking with increase in walking behaviour prior and post milking times. This is to be expected, as cows are moved from and to the pasture, preceding and following milking, to the milking shed where they spent time standing in the holding yard and while being milked.

It appears that the times of sunset and sunrise, and also the removal of cows from pasture for milking, have been found to influence the temporal patterns of several cow behaviours, including grazing, lying, standing and walking. It is important to note however, that several studies have also found significant effects of season (Phillips and Leaver, 1986; Rook and Huckle, 1996) and lactation stage (Phillips and Leaver, 1986; Chaplin and Munksgaard, 2001) on the temporal patterns of behaviour of dairy cows. Although the effects of these factors on the behaviour of dairy cows have not been investigated in the present study, they need to be considered in future work.

The frequency of urination behaviour increased with the increase in grazing frequency, with both urination and grazing following similar temporal patterns throughout the study (see Chapter 2). The association between grazing and urination behaviours can be expected as grazing takes up the largest proportion of the cows' time budget and therefore the time spent grazing is likely to be the time in which animals have most opportunity to urinate. Similarly, lying behaviour accounts for a large part of the time budget of dairy cows in this and other studies (Hardison *et al.,* 1956; O'Connell *et al.,* 1986; Botheras, 2006). However, when cows are lying down they are unable to urinate and this is reflected in the negative relationship between the frequencies of urination and lying behaviour (when no lag + 2 min has been applied to data). Furthermore, there was a weak relationship between the frequencies of urination and standing behaviour in the present study. This may be primarily due to the increase in urination frequency during milking times (Chapter 2) when the frequency of standing behaviour was also found to increase, thus skewing overall results.

The density of grazing, lying, standing and walking behaviours varied and was not uniform within paddocks. The distribution of behavioural variables was also found to be significantly non-random within paddocks. These patterns indicate that different behaviours were carried out in specific areas of the paddock and animals performing a behaviour aggregate in particular place within paddocks. Grazing behaviour, although significantly non-random in its distribution, was the behaviour with the most uniform density within paddocks. Cows tended to graze throughout all areas of paddocks, with some specific preferences, but avoiding mainly the areas along the fences. Staying away from fences may be due to previous exposure of the cows to electric fencing on the farm. Although the fences were not electrified during the study, a previous exposure to electric fences would have resulted in the animals learning to avoid areas that are likely to cause pain (Lee *et al.*, 2009). Fence avoidance may also be perceived and simply be an artefact of GPS accuracy. For example, when cows walk/graze along fence lines the GPS units record locations with a possible radius of 4.7 m, this means that some points may fall outside the fence line. Cows cannot graze outside the fence lines and any such point locations are deleted. As a consequence a smaller number of records are reported for locations immediately adjacent to the fence. Lying and standing behaviours tended to follow similar distribution patterns to each other and followed more pronounced non-uniform density outline than grazing. Cows were observed to stand before and after periods of lying down, with standing behaviour taking place around the same areas where they were recorded to lie. Therefore, this may have lead to the similar distribution patterns of lying and standing behaviour.

The urine patch densities were weakly associated with the density patterns of all behavioural variables. There were some indications that urine patch density was related to the densities of lying (where lag factor of +2 min was applied, see Section 3.2.3.)) and standing behaviour, at least for some of the paddocks. The areas associated with standing and lying are smaller and occupied for longer than any area used for grazing. Therefore, increase in urine patch density within areas used for standing and lying is more likely to result in high N losses due to the potential of urine patch overlap and the consequent exponential rise in the rate of N leaching (Pleasants *et al.*, 2007; Shorten and Pleasants, 2007). It is important to note, however, that results from the present study should be interpreted with caution because there were large variations between paddocks leading to inconsistencies in the overall patterns.

Non-uniform distribution resulting from stock grazing and camping behaviour, is well known and can be caused by contour, water sources, shade and shelter (Petersen *et al.*, 1956; Wilkinson *et al.*, 1989; White *et al.*, 2001; Betteridge *et al.*, 2010a), and on dairy farms particularly, around gateways (Matthew *et al.*, 1988; Saggar *et al.*, 1990 a and b; McDowell, 2006). It is also probable that areas of the paddock with greater pasture cover and/or higher pasture quality may lead livestock to spend longer in these areas than elsewhere, with the probability that nutrient distribution may be similarly biased. In the present study however, there were no clear associations between the patterns of behaviour density and distribution and any of the paddocks' characteristics assessed in this study.

Aspect, elevation and slope did not appear to affect the density of any of the behaviour variables overall. Betteridge *et al.* (2008), studying beef cattle in steep hill country, reported that cows were more likely to stock camp at lower elevation levels that were relatively flat. In contrast to set-stock management, dairy cows are in relatively flat paddocks for a 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. Furthermore, most paddocks in this study had large relatively flat areas which provided sufficient area for foraging and resting without the need to explore the steeper areas.

Unexpectedly, no clear association was found between grazing density and pasture mass. On the whole, the results were surprising as it might have been expected that cows would have spent time in areas with high pasture mass content, in order to maximise intake (Saggar *et al.*, 1990b), resulting in higher grazing densities in these areas. Likewise, Betteridge *et al.* (2008) did not find that pasture mass influenced distribution of sheep, but their paddock had unusually high pasture mass for sheep. Similarly, pasture in this study had a mean mass of 3535 kg DM/ha 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, cows are less likely to spend time searching for areas with high pasture mass and thus are less likely to spend time grazing in these areas.

In general the position of water troughs and paddock gates did not appear to affect the density of any of the behaviour variables. Few studies (White *et al.*, 2001; Matthew *et al.*, 1988; Saggar *et al*., 1990 a and b; McDowell, 2006) and claims made by farmers have indicated that cows tend to congregate around paddock gates and water troughs. However, no note has been made to accurately determine the type of behaviour observed during such congregation. It is not clear, for example, whether cows stand or graze near water troughs or gates. Many farmers have reported that dairy cows spent time standing near gates prior to being moved for milking. Such situation could exist, for example, if forage has been depleted within the paddock. Dairy cows would be then more likely to gather near gateways if forage is in short supply and stand to wait to be taken in for milking. Cows in this study had an adequate pasture allocation however, and forage was not completely depleted during any grazing period. This might explain why there was no clear relationship between behaviour density and gateways in general.

The effects of shade and shelter were not investigated in this study, but other studies (Wilkinson *et al.*, 1989) have shown that shade and shelter can have an effect on animal distribution (Kendall *et al.*, 2006; Tucker *et al.*, 2007). Future studies should investigate the effects of these factors. For example, a portable shade structure, which is moved around, could be used in grazing systems to help manage animal distribution and consequent nutrient redistribution within paddocks.

3.5. Conclusions

1. Motion sensors and GPS units used to study the activity of animals provided data that were comparable to that of other studies with smaller number of dairy cows observed. Dairy cows in this study were observed to have synchronised time budgets that were mainly influenced by milking periods and dusk. The spatial density of grazing, lying, standing and walking activity was non-random in grazed

paddocks, indicating an aggregation of cows engaged in a particular behaviour in specific areas within paddocks.

2. The frequencies of urination and grazing behaviour followed similar temporal patterns, with a positive relationship between urination and grazing behaviour. On the other hand, the frequency of urination decreased with increase in lying activity.
3. The spatial density patterns of behaviour and urine patches indicate that there may be some association between urination and standing, and lying behaviours as these overlap within paddocks. The physical properties of the paddocks did not have an effect on the density of behaviour and urination in this study.

Furthermore, although urination frequencies were low during times spent lying, any urination activity during times of rest may lead to higher N losses and emissions than urination during grazing due to the greater probability of patch overlap within resting areas. Predicting the spatial variability of animal behaviour and consequent localised nutrient distribution may help with the development of more spatially precise fertiliser applications and the improvement of targeted application of N mitigation intervention, such as nitrification inhibitors to N leaching hotspots within paddocks. However, it is important to note that knowing where cows urinate is only part of the question, since N loads in each urination event are likely to change diurnally (Betteridge *et al.*, 1986), but as yet, there is no way to determine this in grazing cows. Modelling animal behaviour and nutrient distribution are discussed in the next chapter.

Chapter Four: Modelling the spatial distribution of urine patches within paddocks on a commercial dairy farm

4.1. Introduction

Ruminant grazing, resting behaviour and excretion lead to nutrient redistribution within and loss from the productive area of pasture. These nutrients are concentrated within dung and urine patches (Haynes and Williams, 1993). Nitrogen return by cattle is mostly concentrated urine (Di and Cameron, 2007). Most N-cycling models for pastoral systems assume uniform return of nutrients to the soil (e.g. Wheeler *et al.*, 2008; Schoumans *et al.*, 2009) to avoid model complexity and lengthy execution time that would be caused by explicit inclusion of urine patches (Snow *et al.*, 2007). However, non-uniform distribution resulting from stock grazing and camping behaviour, has been widely documented (Petersen *et al.*, 1956; Saggar *et al*., 1990 a and b; Stuth, 1991; Franzluebbers *et al.*, 2000; White *et al.*, 2001; McDowell, 2006) and urine deposition in more frequented, preferred camping sites is likely to accelerate N leaching loss. Although there have been some studies investigating aspects of heterogeneous distribution and variability of urine patch N loads in modelling studies (McGechan and Topp, 2004; Pleasants *et al.*, 2007), few studies have explicitly included urine patches (Vellinga *et al.*, 2001; Hutching *et al.*, 2007). Developments of techniques to measure and model urine patch distribution are required to understand the extent of nutrient re-distribution and loss caused by different aspects of dairy cow management. Furthermore, models can be used for predicting and sensitivity testing the effects of alternative management practices on the environment, particularly for mitigating N leaching.

McGechan and Topp (2004) simulated levels of N leaching in dairy cattle in New Zealand. They found that N leaching increased with overall field stocking density and was related to time of year, with the highest levels of N loss during spring (August to October). Pleasants *et al.* (2007) simulated the effects of stocking densities in rotational grazing on the distribution of urine depositions and N leached into ground water. They found that under conditions of relatively high stocking density, losses of N from stock camps were higher due to the greater probability of overlapping urine patches and consequent exponential rise in the rate of N leaching. Heterogeneous urine distribution results in higher rates of localized 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 (Pleasants *et al.*, 2007). Li *et al.* (2001) studied varying N concentrations and urine volume amongst urination events of cows. They found N leaching losses increased logarithmically at paddock level because the amount of N leached was influenced by the amount of urinary N return and N leaching losses increased exponentially with increased N concentration at urine patch level.

Betteridge *et al.* (2008), studying urine distribution by sheep in hill country pasture, modelled the effects of environmental variables on time spent in a location and the spatial distribution of urine patches. Environmental variables such as elevation, aspect and slope were found to contribute to time spent in some locations and thus a skewed urine patch distribution. The spatial urine patch distribution was strongly correlated to the time sheep spent in a particular location (r = 0.82) and a conclusion from their analyses was that it might be possible to predict urine distribution from time spent by sheep at locations within the paddock (Betteridge *et al.*, 2011). Mitigating N losses may become easier if stock camps could be identified so that management practices can target these critical source areas of pollution (Betteridge *et al.*, 2008). In similar hill country on the same farm, the correlation between time beef cows spent at a location with urine patch distribution was smaller (r = 0.54), possibly due to the smaller numbers of cow urination events per day (n = 13) compared with sheep (n = 20.6) (Betteridge *et al.*, 2010b).

The published literature contains no studies that used the behaviour of dairy cows to predict urine patch distribution in a commercial setting. The investigations carried out in Chapters Two and Three showed that the density and distribution of urine patches was heterogeneous across a pasture paddock. The density of grazing, lying, standing and walking behaviours also varied within paddocks. Furthermore, urine patch densities were found to be associated with the density patterns of behavioural variables. In this Chapter the study investigates whether animal behaviour data derived from GPS, IceTag3D® and urine remote sensing tools can be used as indicators to predict urine patch distribution within paddocks in a commercial dairy farm setting. A modelling framework, assessing urine patch distribution in relation to behaviour parameters, is also described in this chapter.

The objective of this study was to:

1. Investigate the potential to use behaviour density data as indicators of urine patch distribution.

4.2. Materials and Methods

The study took place on a commercial dairy farm in Massey University, Palmerston North, New Zealand. Details on herd composition and management have been given in Chapter Two, Section 2.2.

4.2.1. Animal Measurements

Thirty cows were selected from the herd based on position in the herd at milking (i.e. milking order) and age. A detailed explanation of methods used to select and manage cows has been given in Chapter Two, Section 2.2. All animal experimentation was carried out following approval by the Massey University Animal Ethics Committee (Protocols 08/06 and 08/53).

Activity monitors, GPS collars and Urine sensors

Thirty cows, balanced for milking order and age, were selected for the study and were fitted with GPS units and 24 of these were also fitted with urine sensors. A detailed description of equipment and explanation of procedures associated with the GPS collars and urine sensors have been given in Chapter Two, Section 2.2.

Seventeen of the study cows were also fitted with IceTag3D® activity monitors (Ice Robotics, Scotland). A detailed description of equipment and explanation of procedures associated with the IceTag3D activity monitors have been given in Chapter Three, Section 3.3.

4.2.2. Statistical Analysis

The datasets generated in Chapters Two and Three were further analysed in this chapter. Analyses to identify first- and second-order spatial trends in the distribution of urine patches were carried out in Chapter Two and Three. The effects of different parameters, on the urine patch distribution, were also studied in Chapters Two and Three. Based on the results presented in Chapters Two and Three, it was concluded that urine patch distribution followed a heterogeneous point pattern and this distribution may be influenced by behaviour patterns due to associations found between the frequency and density of urine patches and that of each of the recorded behaviour variables. In order to examine the effect of behaviour variables on urine patch distribution further, the data were divided into three categories (grazing periods): 1) AM1, behaviour data collected at pasture between morning and afternoon milking; 2) AM2, behaviour data collected at pasture between afternoon milking and 20:00 h; and 3) PM, behaviour data collected at pasture between 20:00 h and morning milking. These categories reflected the effect of time of day on behaviour frequency (see Chapter Three, Section 3.3). For example, the majority of grazing activity was observed during the AM1 and AM2 periods, while most lying behaviour occurred in the PM period. Categorising data, to reflect the effects of time of day on behaviour, allowed the examination of how spatial distribution of urine patches and density of behaviour were associated at times when the frequency of specific behaviour was high.

Breman and Turner (1992) and Baddeley and Turner (2000) developed a statistical package *Spatstat* in the R language (R 2.10.1 for Windows, R Development Core Team 2010) for analysing point patterns in two dimensions. An important goal of *Spatstat* is to provide a generic framework to allow models to be fitted to spatial point pattern data. Although methods for fitting point process models have been available since the 1970s (Besag and Diggle, 1977; Ripley, 1988; Diggle, 2003; Moller and Waagepetersen, 2003) most of the methods that have been developed were, in general, specific to the data sets that provided the motivation for model development in the first place. Furthermore, up until recently there were no software implementations of sufficient generality to fit appropriate models to real datasets. The scope of modelling capacity under *Spatstat* is very wide and includes facilities to include terms to account for spatial trends, covariates, and dependence-on-marks. Therefore, *Spatstat* was chosen to use to fit a ‘point-to-point’ interaction terms with spatial covariates.

An inhomogeneous Poisson process model (PPM) from *Spatstat* was chosen for this study (see Baddeley and Turner, 2005; Baddeley, 2008, 2010). The general form of such a model is:

$$\sigma(u) = \exp\left(\beta_0 + \beta_1 Z(u_{1i})(u))(u_{1i}) + \cdots + \beta_m Z(u_{mi})\right)$$

where $\sigma(u)$ is the intensity of the inhomogeneous Poisson model, $\beta_0 \text{ and } \beta_1$ outcome of interest (the number of urine patches per unit area), β_0 is an intercept term (representing the mean number of urine patches per unit area across the entire study area) and $\beta_1 \ldots \beta_m$ are m regression coefficients quantifying the effect of the intensity of m behaviours, $Z(u_{1i})$ to $Z(u_{mi})$, on the outcome.

The behaviour covariates used in the model were grazing, lying, standing and walking. These were presented as a list of pixel arrays, each array containing the densities of these behaviours as calculated in Chapter Three using kernel smoothing (R Development Core Team, New Zealand). A ‘lag’ factor of +2 min was applied to lying behaviour data, when kernel smoothing images were made, in order to incorporate urine deposits that normally follow long periods of lying (Phillips, 1993; Betteridge K., personal communication).

After a point process model was fitted the model was checked for goodness of fit. Model checking can be either: 1) ‘formal’, based on probabilistic assumptions about that data and allows for probabilistic statements about outcome (e.g. hypothesis tests) or 2) ‘informal’, using tools that do not impose assumptions on the data and interpretation depends on human judgment (e.g. residual interpretation). A residual was defined for each observation by (residual) = (observed) – (fitted) and if the model was a good fit, the residual centred around zero (Baddeley, 2008). Both methods were used to check the fit of the models developed in this study.

A chi-squared test was used as a formal test of the null hypothesis that, taken together, the behaviour covariates contribute significantly to the model outcome, the number of urine patches per unit area. A significance level of 0.05 was used. On the other hand, residual counts were used to informally inspect the fit of a model (Baddeley, 2008).

4.3. Results

Relationship between the density of behavioural variables and urine patch density

Grazing behaviour and urine patch densities were positively correlated and showed the greatest consistency between paddocks when compared to associations of lying, standing and walking behaviour variables for the AM1 period (Table 4.1). Associations were weak across all behaviour variables for paddocks 61 and 79, for the same grazing period, in contrast to patterns observed in the rest of the paddocks where at least one or two behaviour variables showed moderate associations with urine patch density.

Table 4.1. Correlation coefficients and their significance between urine patch density and the density of behaviour variables for data collected at pasture between morning and afternoon milking (AM1).

Paddock	**Grazing *r*[†]**	***P*-value**	**Lying *r*[†]**	***P*-value**	**Standing *r*[†]**	***P*-value**	**Walking *r*[†]**	***P*-value**
6	0.20	<0.0001	0.23	<0.0001	0.26	<0.0001	0.37	<0.0001
7a	0.43	<0.0001	0.36	<0.0001	0.42	<0.0001	0.08	<0.001
17a	0.62	<0.0001	-0.04	>0.05	0.69	<0.0001	0.63	<0.0001
29a	0.13	<0.001	0.54	<0.0001	0.35	<0.0001	0.42	<0.0001
61	0.13	<0.001	0.21	<0.0001	-0.14	<0.05	0.10	<0.05
79	0.28	<0.0001	0.17	<0.001	0.04	>0.05	-0.06	>0.05

[†] *r* = Correlation coefficient.

For the AM2 period, the densities of most behavioural variables were again positively correlated with the density of urine patches, although the correlations were weak overall

(Table 4.2). Two exceptions were the negative association between the density of lying and the urine patch density, and the positive moderate correlation between walking and the density of urine patches (paddock 78). Relationships between the density of urine patches and density of behaviour variables in paddock 62 though significant, were weak. Patterns of associations were weaker for the AM2 period than the AM1 period.

Table 4.2. Correlation coefficients and their significance between urine patch density and the density of behaviour variables for data collected at pasture between afternoon milking and 20:00 (AM2).

Paddock	**Grazing $r^{\dagger}$**	***P*-value**	**Lying $r^{\dagger}$**	***P*-value**	**Standing $r^{\dagger}$**	***P*-value**	**Walking $r^{\dagger}$**	***P*-value**
7b	0.24	<0.0001	0.04	<0.05	0.36	<0.0001	0.13	<0.0001
17b	0.16	<0.0001	0.03	<0.001	0.04	<0.001	0.24	<0.001
29b	0.35	<0.0001	0.22	<0.0001	0.28	<0.0001	0.07	<0.001
60	0.08	<0.001	0.11	<0.0001	0.42	<0.0001	0.01	<0.05
62	0.05	<0.05	0.03	<0.05	0.08	<0.05	0.04	<0.001
78	0.40	<0.0001	-0.12	<0.0001	0.11	<0.0001	0.63	<0.0001

$^{\dagger}r$ = Correlation coefficient.

The densities of all behaviour variables were positively associated with the density of urine patches for the PM period (Table 4.3). The strongest correlations between behaviour variables and urine patch density were observed in paddocks 62 and 78, while weakest associations were detected in paddock 29b. Patterns of associations were most consistent in the PM grazing period with patterns being the least definitive in the AM2 period.

Table 4.3. Correlation coefficients and their significance between urine patch density and the density of behaviour variables for data collected at pasture between 20:00 and morning milking (PM).

Paddock	**Grazing *r*†**	***P*-value**	**Lying *r*†**	***P*-value**	**Standing *r*†**	***P*-value**	**Walking *r*†**	***P*-value**
7b	0.33	<0.0001	0.38	<0.0001	0.54	<0.0001	0.36	<0.0001
17b	0.37	<0.0001	0.34	<0.0001	0.44	<0.0001	0.47	<0.0001
29b	0.25	<0.0001	0.26	<0.0001	0.15	<0.0001	0.28	<0.0001
60	0.18	<0.0001	0.33	<0.0001	0.25	<0.0001	0.48	<0.0001
62	0.50	<0.0001	0.48	<0.0001	0.69	<0.0001	0.60	<0.0001
78	0.22	<0.0001	0.45	<0.0001	0.59	<0.0001	0.54	<0.0001

†*r* = Correlation coefficient.

Poisson process model

Results of the fitted PPM, the probabilistic assumptions and the residual diagnostics from the model are presented in Tables 4.4 to 4.15. The behaviour covariates grazing, lying, standing and walking were better indicators of urine patch distribution for PM grazing periods than AM1 and AM2 periods. Behaviour covariates were significant predictors of urine patch distribution for the PM grazing period for all paddocks (Tables 4.6b, 4.8b, 4.10b, 4.11b, 4.13b and 4.14b). Although the formal model testing indicates the model to be true, informal testing identified some inconsistencies. For example, fitting urine patch data as a function of standing behaviour in paddock 7b (Table 4.6b) (PM period) was statistically significant indicating the model to be true. Nevertheless, the 'lurking variable'[1] plots for x coordinate suggest a lack of fit at about x = 27322 and the image of the smooth residual field implies an excess of positive residuals at the same coordinate, both indicating that the model underestimates the true intensity of points in this area of paddock 7b. It is important to note however, that the increase in positive residuals was very small (<0.0004 increase in intensity).

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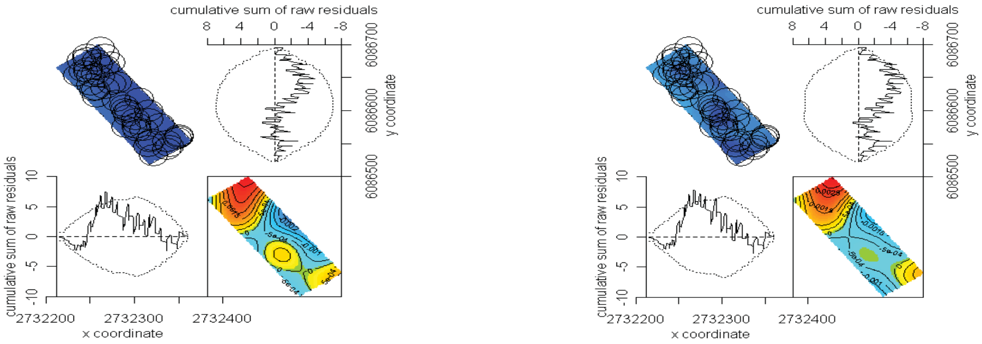
[1] The plot displays the kernel-weighted average of the residuals (urine patches) plotted against the covariate (behaviour). The empirical plot (thick solid lines) is shown together with its expected values assuming the model is true (dashed line) and the pointwise two-standard-deviation limits (thin solid lines). The plot can be used to reveal departure from the fitted model, in particular that the point pattern depends on the covariate.

Results of the PPM for the AM1 and AM2 grazing periods were less clear. Behaviour covariates did not have uniform effect on urine patch distribution and their significance varied from paddock to paddock within the AM1 and AM2 periods (Tables 4.4, 4.5, 4.6a, 4.7, 4.8a, 4.9, 4.10a, 4.11a, 4.12, 4.13a, 4.14a and 4.15). For example, grazing was a poor predictor of urine patch distribution in paddock 6, AM1 period (Table 4.4). However, the same behaviour covariate had a significant effect on urine patch distribution in paddock 7a for the same grazing period (Table 4.5). Lying was a poor overall predictor of urine patch distribution for AM1 and AM2 periods, and lying was a significant behaviour covariate in only three paddocks (Tables 4.4, 4.7 and 4.10a). There was no clear pattern of the effect of standing and walking on urine patch distribution for either the AM1 or AM2 period. Furthermore, urine patch distribution in paddocks 61, 62 (AM2 period only) and 79 could not be fitted as a function of any of the four behaviour variables (Tables 4.12, 4.13a and 4.15).

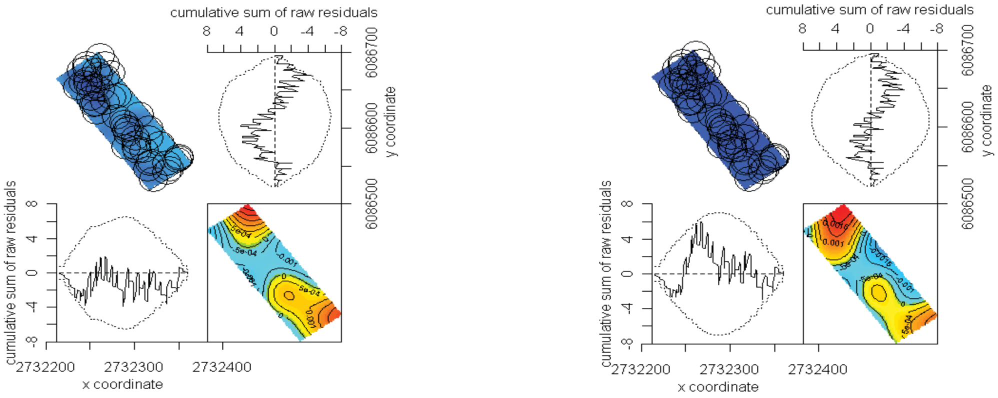
Table 4.4. Fitted inhomogeneous Poisson process model with estimated intensities of urine distribution which were function of the spatial covariates (Grazing, Lying, Standing and Walking); chi-squared test applied to the fitted model and residual diagnostic plots from the fitted model in paddock 6, AM1 period.

Paddock	AM/PM	Variable	Estimate[§] (SE[‡])	95% CI[*]	X^{2}[**]	P-value
6	AM1[†]	Intercept	-5.83 (0.38)			
		Grazing density	1.20 (0.90)	-0.57 to 2.97	1.8	>0.05
		Intercept	-5.86 (0.25)			
		Lying density	9.08 (3.44)	2.34 to 15.83	7.0	**<0.01**
		Intercept	-5.80 (0.24)			
		Standing density	2.80 (1.17)	0.51 to 5.09	5.8	**<0.05**
		Intercept	-5.53 (0.21)			
		Walking density	0.82 (0.75)	-0.65 to 2.28	1.2	>0.05



Grazing

Standing



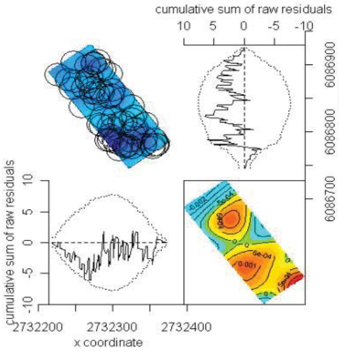
Lying

Walking

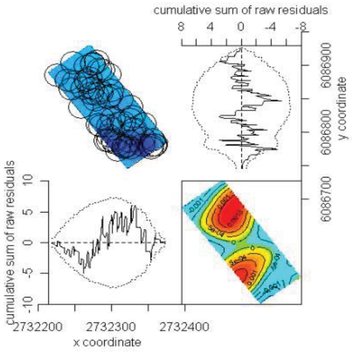
[†]AM: based on behaviour data at pasture between morning and afternoon milking. [§]Estimate: estimated intensity function of fitted coefficients. [‡]SE: Standard error of fitted intensity. [*]CI: Confidence intervals of fitted intensity. [**]X^2: chi-squared goodness-of-fit test. Interpretation of diagnostic plots: Top left panel – circles represent data points of urine, colour scheme represents fitted intensity. Colour intensity should follow circle intensity if the model was true; bottom right panel – smoothed residual field based on kernel estimate of urine patch intensity of the fitted model. The difference should be approximately zero if the model was true; two other panels – lurking variable plots against spatial coordinates with 5% significance bands. The residual line should be within the significance bands and approximately zero if the model was true.

Table 4.5. Fitted inhomogeneous Poisson process model with estimated intensities of urine distribution which were function of the spatial covariates (Grazing, Lying, Standing and Walking), chi-squared test applied to the fitted model and residual diagnostic plots from the fitted model in paddock 7a, AM1 period.

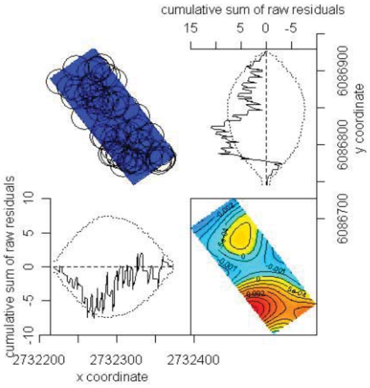
Paddock	AM/PM	Variable	Estimate (SE[‡])	95% CI[*]	X^{2**}	P-value
7a	AM1[†]	Intercept	-6.65 (0.37)			
		Grazing density	3.55 (0.86)	1.88 to 5.23	17.2	**<0.0001**
		Intercept	-5.41 (0.18)			
		Lying density	2.24 (3.58)	-4.78 to 9.26	0.39	>0.05
		Intercept	-5.73 (0.18)			
		Standing density	3.05 (0.79)	1.51 to 4.59	15.1	**0.0001**
		Intercept	-5.68 (0.17)			
		Walking density	1.92 (0.49)	0.97 to 2.87	15.7	**<0.0001**



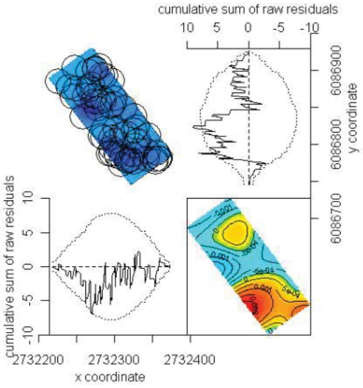
Grazing



Standing



Lying

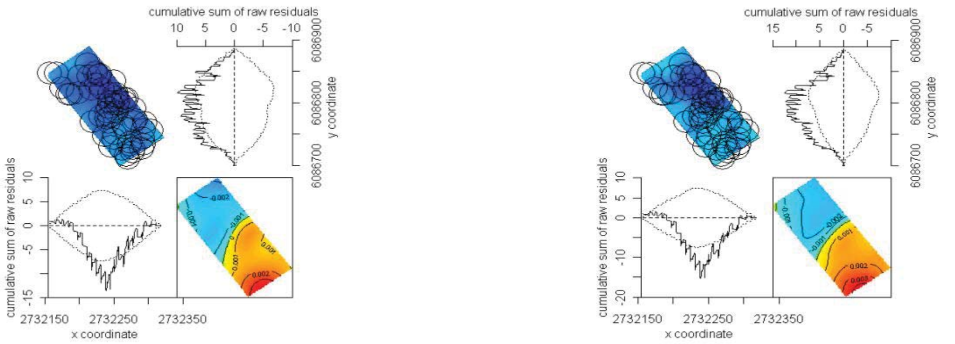


Walking

[†] AM: based on behaviour data at pasture between morning and afternoon milking. [§] Estimate: estimated intensity function of fitted coefficients. [‡] SE: Standard error of fitted intensity. [*] CI: Confidence intervals of fitted intensity. [**] X^2: chi-squared goodness-of-fit test. Interpretation of diagnostic plots: Top left panel – circles represent data points of urine, colour scheme represents fitted intensity. Colour intensity should follow circle intensity if the model was true; bottom right panel – smoothed residual field based on kernel estimate of urine patch intensity of the fitted model. The difference should be approximately zero if the model was true; two other panels – lurking variable plots against spatial coordinates with 5% significance bands. The residual line should be within the significance bands and approximately zero if the model was true.

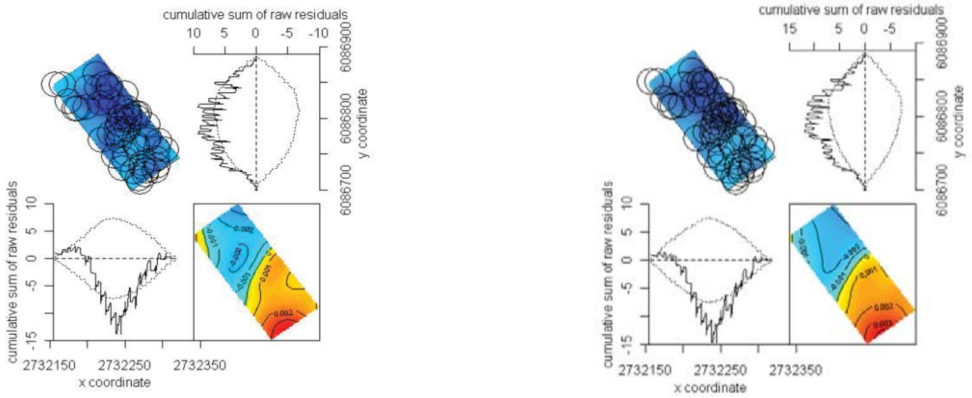
Table 4.6a. Fitted inhomogeneous Poisson process model with estimated intensities of urine distribution which were function of the spatial covariates (Grazing, Lying, Standing and Walking), chi-squared test applied to the fitted model and residual diagnostic plots from the fitted model in paddock 7b, AM2 period.

Paddock	AM/PM	Variable	Estimate (SE[‡])	95% CI[*]	X^{2}[**]	P-value
7b	AM2[†]	Intercept	-6.09 (0.32)			
		Grazing density	1.97 (0.92)	0.16 to 3.77	4.6	<0.05
		Intercept	-5.52 (0.19)			
		Lying density	1.32 (17.80)	-33.58 to 36.22	0.0055	**>0.05**
		Intercept	-5.81 (0.19)			
		Standing density	5.31 (2.03)	1.33 to 9.28	6.8	<0.01
		Intercept	-5.57 (0.15)			
		Walking density	1.70 (1.37)	-0.99 to 4.38	1.5	**>0.05**



Grazing

Standing



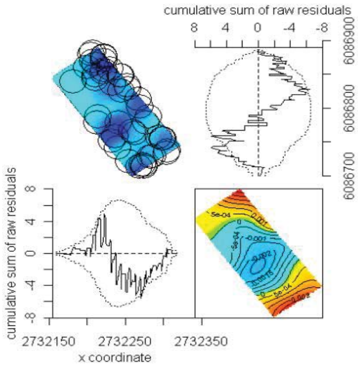
Lying

Walking

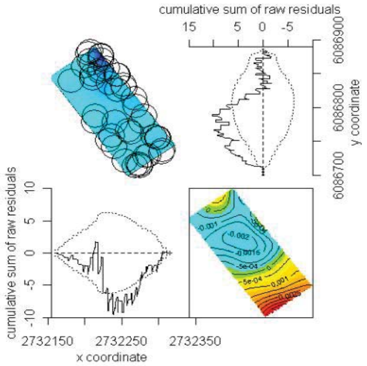
[†] AM2: based on behaviour data at pasture between afternoon milking and 20:00. [§] Estimate: estimated intensity function of fitted coefficients. [‡] SE: Standard error of fitted intensity. [*] CI: Confidence intervals of fitted intensity. [**] X^2: chi-squared goodness-of-fit test. Interpretation of diagnostic plots: Top left panel – circles represent data points of urine, colour scheme represents fitted intensity. Colour intensity should follow circle intensity if the model was true; bottom right panel – smoothed residual field based on kernel estimate of urine patch intensity of the fitted model. The difference should be approximately zero if the model was true; two other panels – lurking variable plots against spatial coordinates with 5% significance bands. The residual line should be within the significance bands and approximately zero if the model was true.

Table 4.6b. Fitted inhomogeneous Poisson process model with estimated intensities of urine distribution which were function of the spatial covariates (Grazing, Lying, Standing and Walking), chi-squared test applied to the fitted model and residual diagnostic plots from the fitted model in paddock 7b, PM period.

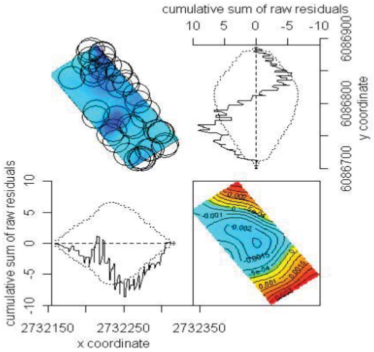
Paddock	AM/PM	Variable	Estimate (SE[‡])	95% CI[*]	X^{2**}	P-value
7b	PM[†]	Intercept	-6.23 (0.22)			
		Grazing density	5.68 (1.55)	2.64 to 8.72	13.4	**<0.001**
		Intercept	-6.14 (0.20)			
		Lying density	13.32 (3.03)	7.39 to 19.26	19.4	**<0.0001**
		Intercept	-6.18 (0.19)			
		Standing density	2.23 (0.36)	1.52 to 2.93	38.6	**<0.0001**
		Intercept	-6.19 (0.21)			
		Walking density	0.81 (0.20)	0.41 to 1.20	16.0	**<0.0001**



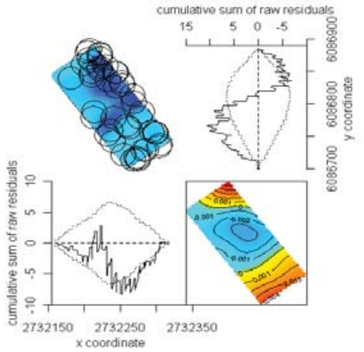
Grazing



Standing



Lying

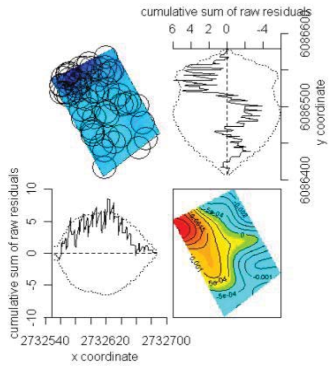


Walking

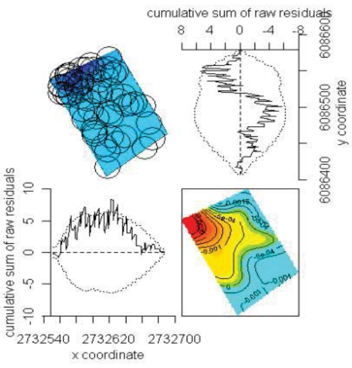
[†]PM: based on behaviour data at pasture from 20:00 until morning milking. [§]Estimate: estimated intensity function of fitted coefficients. [‡]SE: Standard error of fitted intensity. [*]CI: Confidence intervals of fitted intensity. [**]X^2: chi-squared goodness-of-fit test. Interpretation of diagnostic plots: Top left panel – circles represent data points of urine, colour scheme represents fitted intensity. Colour intensity should follow circle intensity if the model was true; bottom right panel – smoothed residual field based on kernel estimate of urine patch intensity of the fitted model. The difference should be approximately zero if the model was true; two other panels – lurking variable plots against spatial coordinates with 5% significance bands. The residual line should be within the significance bands and approximately zero if the model was true.

Table 4.7. Fitted inhomogeneous Poisson process model with estimated intensities of urine distribution which were function of the spatial covariates (Grazing, Lying, Standing and Walking), chi-squared test applied to the fitted model and residual diagnostic plots from the fitted model in paddock 17a, AM1 period.

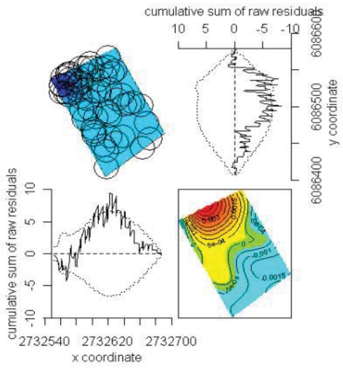
Paddock	AM/PM	Variable	Estimate[§] (SE[‡])	95% CI[*]	X^{2**}	P-value
17a	AM1[†]	Intercept	-6.27 (0.25)			
		Grazing density	2.00 (0.40)	1.21 to 2.79	24.6	**<0.0001**
		Intercept	-5.67 (0.16)			
		Lying density	6.23 (1.30)	3.68 to 8.77	23.0	**<0.0001**
		Intercept	-5.76 (0.17)			
		Standing density	2.03 (0.40)	1.24 to 2.81	25.8	**<0.000**
		Intercept	-5.39 (0.15)			
		Walking density	0.11 (0.79)	-1.43 to 1.65	0.02	>0.05



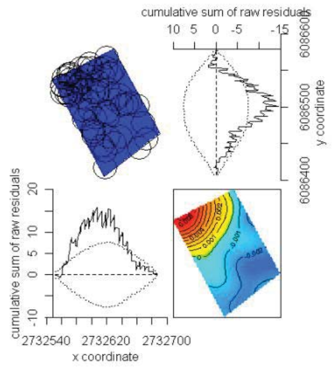
Grazing



Standing



Lying

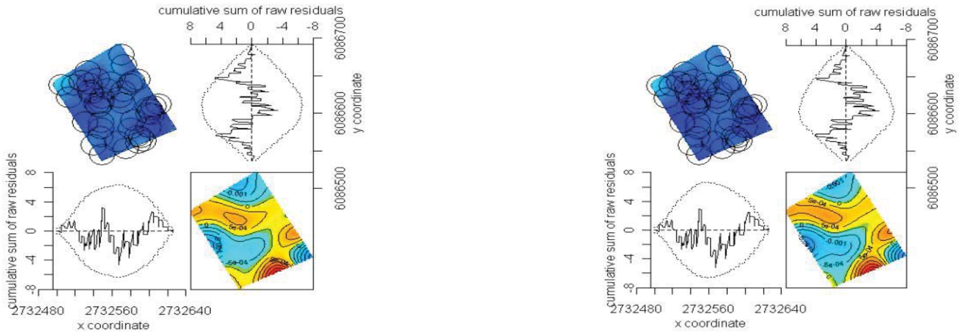


Walking

[†] AM: based on behaviour data at pasture between morning and afternoon milking. [§] Estimate: estimated intensity function of fitted coefficients. [‡] SE: Standard error of fitted intensity. [*] CI: Confidence intervals of fitted intensity. [**] X^2: chi-squared goodness-of-fit test. Interpretation of diagnostic plots: Top left panel – circles represent data points of urine, colour scheme represents fitted intensity. Colour intensity should follow circle intensity if the model was true; bottom right panel – smoothed residual field based on kernel estimate of urine patch intensity of the fitted model. The difference should be approximately zero if the model was true; two other panels – lurking variable plots against spatial coordinates with 5% significance bands. The residual line should be within the significance bands and approximately zero if the model was true.

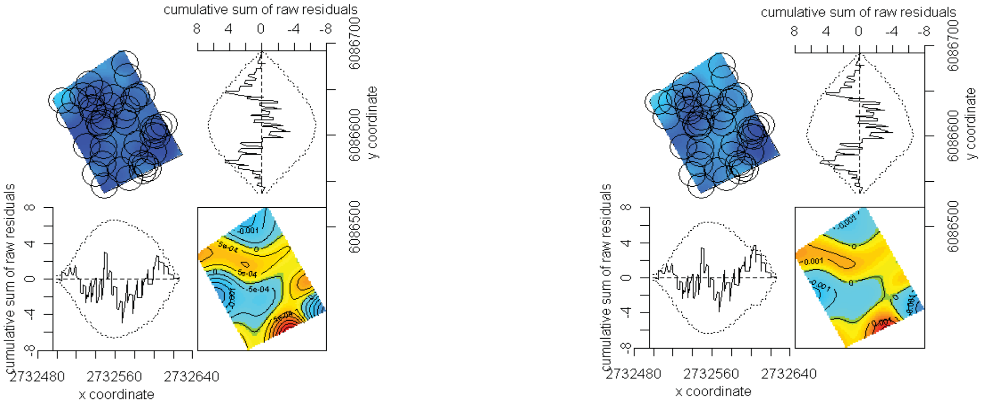
Table 4.8a. Fitted inhomogeneous Poisson process model with estimated intensities of urine distribution which were function of the spatial covariates (Grazing, Lying, Standing and Walking), chi-squared test applied to the fitted model and residual diagnostic plots from the fitted model in paddock 17b, AM2 period.

Paddock	AM/PM	Variable	Estimate (SE[‡])	95% CI[*]	X^2[**]	P-value
17b	AM2[†]	Intercept	-6.34 (0.55)			
		Grazing density	2.35 (1.50)	-0.59 to 5.29	2.5	>0.05
		Intercept	-5.64 (0.23)			
		Lying density	18.67 (31.84)	-43.73 to 81.07	0.34	>0.05
		Intercept	-5.54 (0.25)			
		Standing density	0.88 (5.39)	-10.47 to 10.65	0.0003	>0.05
		Intercept	-5.73 (0.18)			
		Walking density	3.33 (1.42)	0.55 to 6.11	5.5	**<0.05**



Grazing

Standing



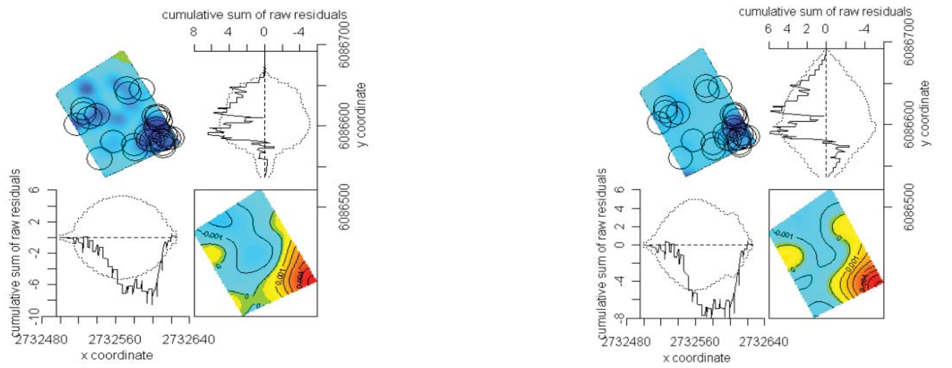
Lying

Walking

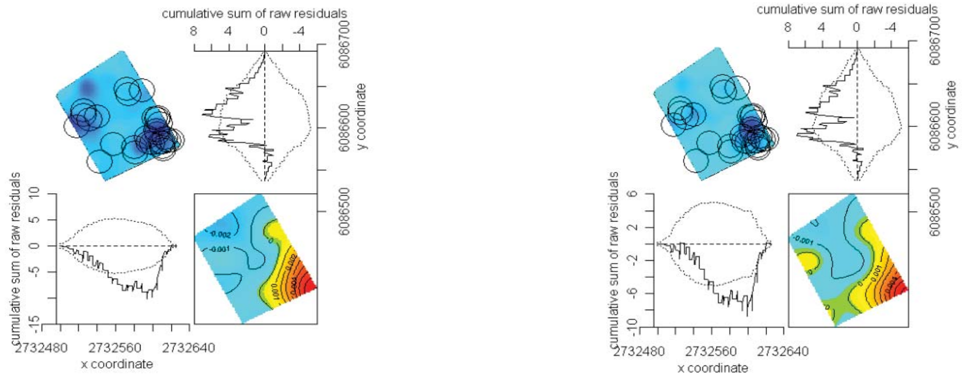
[†]AM: based on behaviour data at pasture from afternoon milking until 20:00. [§]Estimate: estimated intensity function of fitted coefficients. [‡]SE: Standard error of fitted intensity. [*]CI: Confidence intervals of fitted intensity. [**]X^2: chi-squared goodness-of-fit test. Interpretation of diagnostic plots: Top left panel – circles represent data points of urine, colour scheme represents fitted intensity. Colour intensity should follow circle intensity if the model was true; bottom right panel – smoothed residual field based on kernel estimate of urine patch intensity of the fitted model. The difference should be approximately zero if the model was true; two other panels – lurking variable plots against spatial coordinates with 5% significance bands. The residual line should be within the significance bands and approximately zero if the model was true.

Table 4.8b. Fitted inhomogeneous Poisson process model with estimated intensities of urine distribution which were function of the spatial covariates (Grazing, Lying, Standing and Walking), chi-squared test applied to the fitted model and residual diagnostic plots from the fitted model in paddock 17b, PM period.

Paddock	AM/PM	Variable	Estimate (SE[‡])	95% CI[*]	X^{2**}	P-value
17b	PM[†]	Intercept	-6.46 (0.26)			
		Grazing density	8.35 (2.24)	3.96 to 12.74	13.9	**<0.001**
		Intercept	-6.52 (0.27)			
		Lying density	12.73 (3.48)	5.90 to 19.56	13.3	**<0.001**
		Intercept	-6.44 (0.25)			
		Standing density	7.61 (1.76)	4.17 to 11.06	18.8	**<0.0001**
		Intercept	-6.79 (0.29)			
		Walking density	0.75 (0.14)	0.48 to 1.03	28.5	**<0.0001**



Grazing Standing

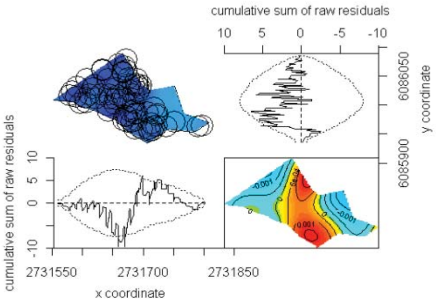


Lying Walking

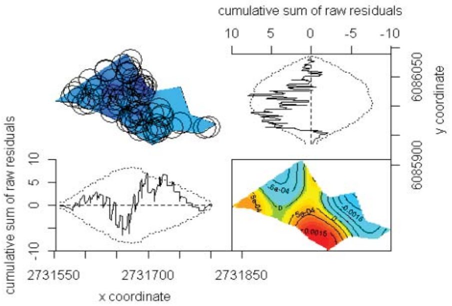
[†]PM: based on behaviour data at pasture from 20:00 until morning milking. [§]Estimate: estimated intensity function of fitted coefficients. [‡]SE: Standard error of fitted intensity. [*]CI: Confidence intervals of fitted intensity. [**]X^2: chi-squared goodness-of-fit test. Interpretation of diagnostic plots: Top left panel – circles represent data points of urine, colour scheme represents fitted intensity. Colour intensity should follow circle intensity if the model was true; bottom right panel – smoothed residual field based on kernel estimate of urine patch intensity of the fitted model. The difference should be approximately zero if the model was true; two other panels – lurking variable plots against spatial coordinates with 5% significance bands. The residual line should be within the significance bands and approximately zero if the model was true.

Table 4.9. Fitted inhomogeneous Poisson process model with estimated intensities of urine distribution which were function of the spatial covariates (Grazing, Lying, Standing and Walking), chi-squared test applied to the fitted model and residual diagnostic plots from the fitted model in paddock 29a, AM1 period.

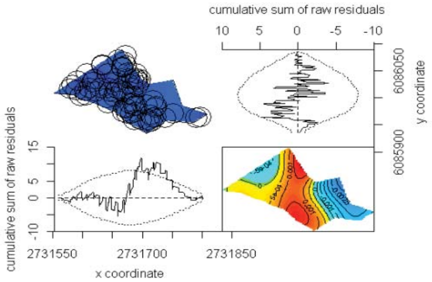
Paddock	AM/PM	Variable	Estimate[§] (SE[‡])	95% CI[*]	X^{2**}	P-value
29a	AM1[†]	Intercept	-5.97 (0.24)			
		Grazing density	1.95 (0.65)	0.67 to 3.22	9.0	**<0.01**
		Intercept	-5.53 (0.15)			
		Lying density	5.72 (4.50)	-3.10 to 14.54	1.6	**<0.05**
		Intercept	-5.80 (0.17)			
		Standing density	3.58 (0.91)	1.80 to 5.36	15.5	**<0.0001**
		Intercept	-5.53 (0.15)			
		Walking density	0.63 (0.48)	-0.30 to 1.56	1.7	>0.05



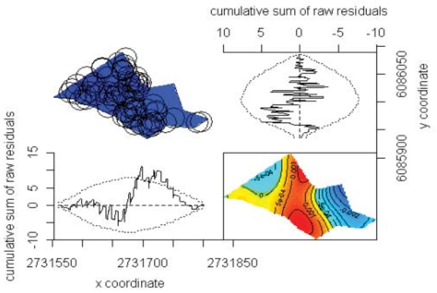
Grazing



Standing



Lying

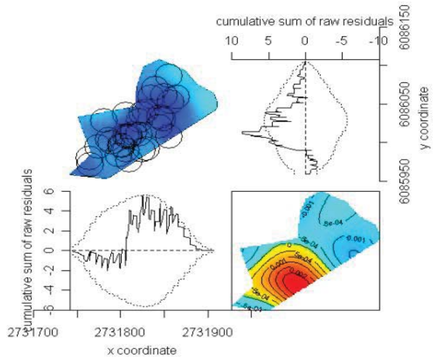


Walking

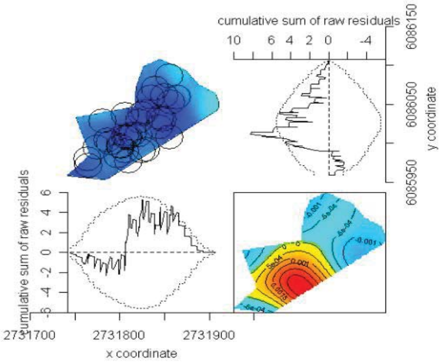
[†] AM: based on behaviour data at pasture between morning and afternoon milking. [§] Estimate: estimated intensity function of fitted coefficients. [‡] SE: Standard error of fitted intensity. [*] CI: Confidence intervals of fitted intensity. [**] X^2: chi-squared goodness-of-fit test. Interpretation of diagnostic plots: Top left panel – circles represent data points of urine, colour scheme represents fitted intensity. Colour intensity should follow circle intensity if the model was true; bottom right panel – smoothed residual field based on kernel estimate of urine patch intensity of the fitted model. The difference should be approximately zero if the model was true; two other panels – lurking variable plots against spatial coordinates with 5% significance bands. The residual line should be within the significance bands and approximately zero if the model was true.

Table 4.10a. Fitted inhomogeneous Poisson process model with estimated intensities of urine distribution which were function of the spatial covariates (Grazing, Lying, Standing and Walking), chi-squared test applied to the fitted model and residual diagnostic plots from the fitted model in paddock 29b, AM2 period.

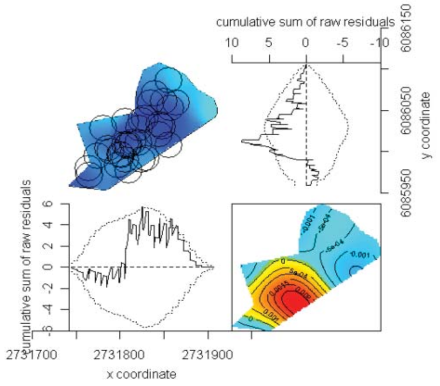
Paddock	AM/PM	Variable	Estimate (SE[‡])	95% CI[*]	X^2[**]	P-value
29b	AM2[†]	Intercept	-7.36 (0.54)			
		Grazing density	4.91 (1.59)	1.79 to 8.04	9.5	**<0.01**
		Intercept	-6.39 (0.28)			
		Lying density	45.53 (19.36)	7.59 to 83.47	5.5	**<0.05**
		Intercept	-6.23 (0.25)			
		Standing density	8.00 (4.32)	-0.46 to 16.46	3.4	>0.05
		Intercept	-5.98 (0.20)			
		Walking density	2.46 (5.11)	-7.54 to 12.47	0.23	>0.05



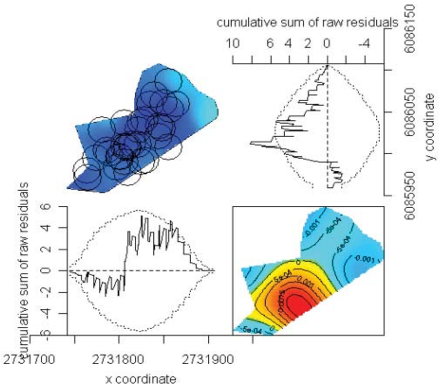
Grazing



Standing



Lying

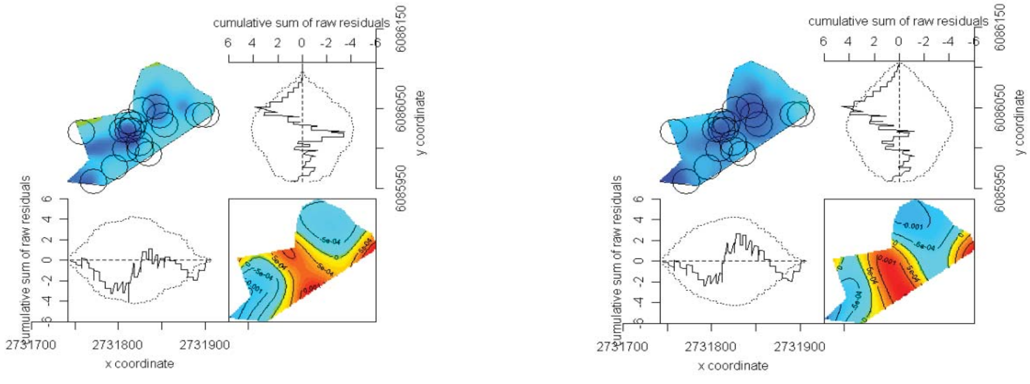


Walking

[†]AM: based on behaviour data at pasture from afternoon milking until 20:00. [§]Estimate: estimated intensity function of fitted coefficients. [‡]SE: Standard error of fitted intensity. [*]CI: Confidence intervals of fitted intensity. [**]X^2: chi-squared goodness-of-fit test. Interpretation of diagnostic plots: Top left panel – circles represent data points of urine, colour scheme represents fitted intensity. Colour intensity should follow circle intensity if the model was true; bottom right panel – smoothed residual field based on kernel estimate of urine patch intensity of the fitted model. The difference should be approximately zero if the model was true; two other panels – lurking variable plots against spatial coordinates with 5% significance bands. The residual line should be within the significance bands and approximately zero if the model was true.

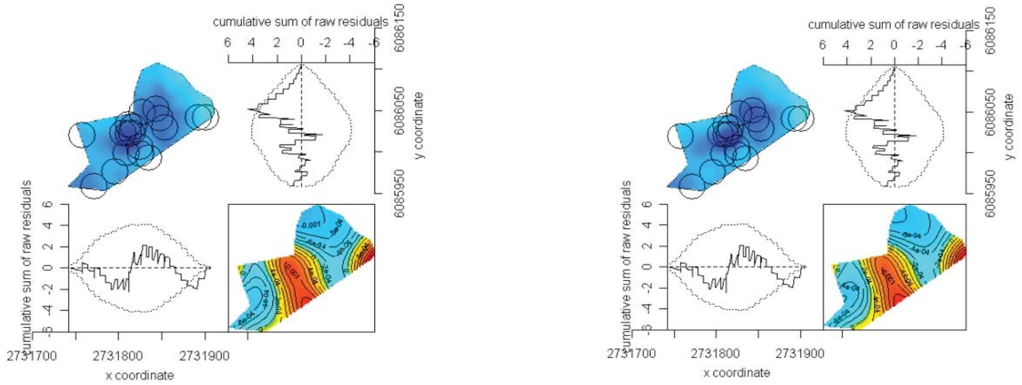
Table 4.10b. Fitted inhomogeneous Poisson process model with estimated intensities of urine distribution which were function of the spatial covariates (Grazing, Lying, Standing and Walking), chi-squared test applied to the fitted model and residual diagnostic plots from the fitted model in paddock 29b, PM period.

Paddock	AM/PM	Variable	Estimate (SE[‡])	95% CI[*]	X^{2**}	P-value
29b	PM[†]	Intercept	-7.11 (0.38)			
		Grazing density	11.20 (4.61)	2.17 to 20.24	5.9	**<0.05**
		Intercept	-6.72 (0.28)			
		Lying density	10.13 (5.15)	0.04 to 20.23	3.9	**<0.05**
		Intercept	-6.80 (0.30)			
		Standing density	7.46 (3.89)	-0.17 to 15.09	3.7	>0.05
		Intercept	-6.80 (0.29)			
		Walking density	0.51 (0.21)	0.11 to 0.92	6.1	**<0.05**



Grazing

Standing



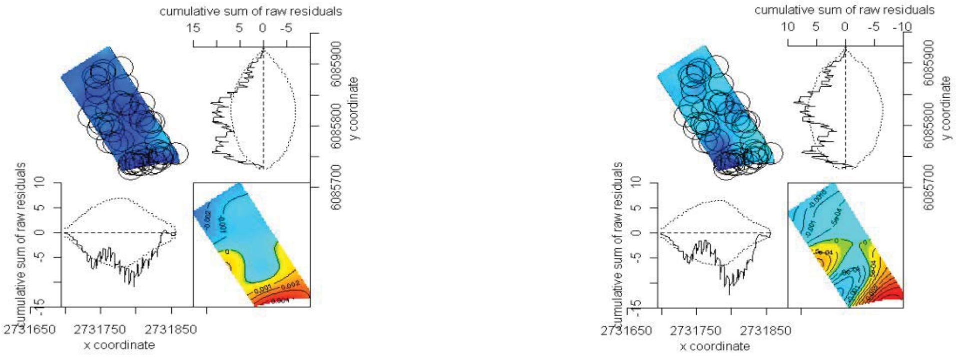
Lying

Walking

[†]PM: based on behaviour data at pasture from 20:00 until morning milking. [§]Estimate: estimated intensity function of fitted coefficients. [‡]SE: Standard error of fitted intensity. [*]CI: Confidence intervals of fitted intensity. [**]X^2: chi-squared goodness-of-fit test. Interpretation of diagnostic plots: Top left panel – circles represent data points of urine, colour scheme represents fitted intensity. Colour intensity should follow circle intensity if the model was true; bottom right panel – smoothed residual field based on kernel estimate of urine patch intensity of the fitted model. The difference should be approximately zero if the model was true; two other panels – lurking variable plots against spatial coordinates with 5% significance bands. The residual line should be within the significance bands and approximately zero if the model was true.

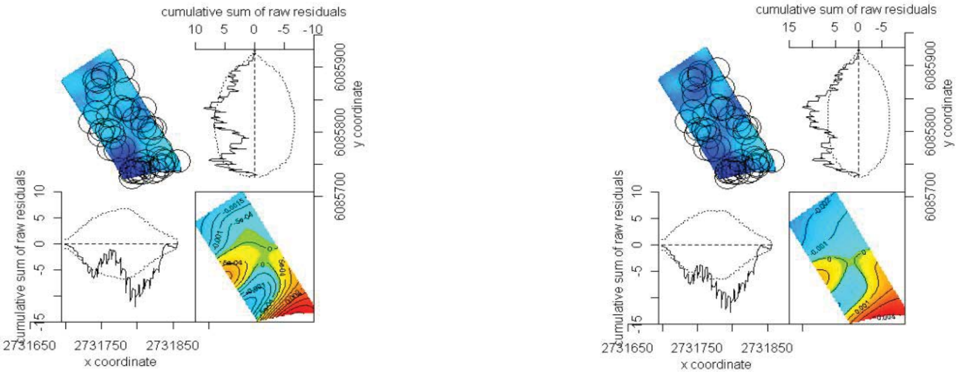
Table 4.11a. Fitted inhomogeneous Poisson process model with estimated intensities of urine distribution which were function of the spatial covariates (Grazing, Lying, Standing and Walking), chi-squared test applied to the fitted model and residual diagnostic plots from the fitted model in paddock 60, AM2 period.

Paddock	AM/PM	Variable	Estimate[§] (SE[‡])	95% CI[*]	X^{2}[**]	P-value
60	AM2[†]	Intercept	-5.98 (0.30)			
		Grazing density	0.83 (1.26)	-1.65 to 3.31	0.43	>0.05
		Intercept	-5.65 (0.18)			
		Lying density	-60.43 (46.70)	-151.96 to 31.11	1.7	>0.05
		Intercept	-6.17 (0.18)			
		Standing density	4.68 (1.03)	2.66 to 6.70	20.7	**<0.0001**
		Intercept	-5.80 (0.15)			
		Walking density	-0.37 (3.81)	-7.84 to 7.10	0.0093	>0.05



Grazing

Standing



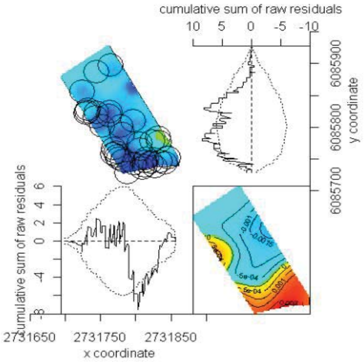
Lying

Walking

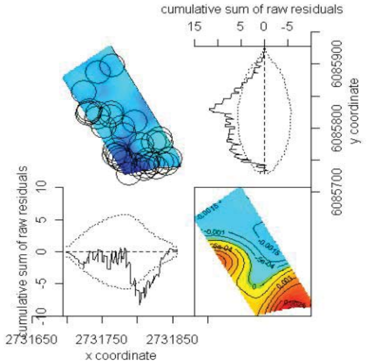
[†]AM: based on behaviour data at pasture from afternoon milking until 20:00. [§]Estimate: estimated intensity function of fitted coefficients. [‡]SE: Standard error of fitted intensity. [*]CI: Confidence intervals of fitted intensity. [**]X^{2}: chi-squared goodness-of-fit test. Interpretation of diagnostic plots: Top left panel – circles represent data points of urine, colour scheme represents fitted intensity. Colour intensity should follow circle intensity if the model was true; bottom right panel – smoothed residual field based on kernel estimate of urine patch intensity of the fitted model. The difference should be approximately zero if the model was true; two other panels – lurking variable plots against spatial coordinates with 5% significance bands. The residual line should be within the significance bands and approximately zero if the model was true.

Table 4.11b. Fitted inhomogeneous Poisson process model with estimated intensities of urine distribution which were function of the spatial covariates (Grazing, Lying, Standing and Walking), chi-squared test applied to the fitted model and residual diagnostic plots from the fitted model in paddock 60, PM period.

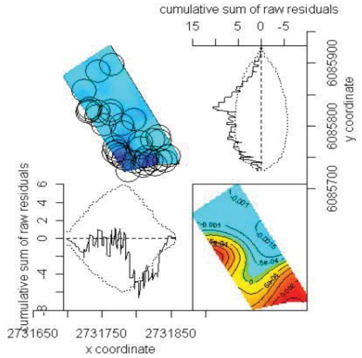
Paddock	AM/PM	Variable	Estimate (SE[‡])	95% CI[*]	X^{2**}	P-value
60	PM[†]	Intercept	-6.56 (0.31)			
		Grazing density	5.69 (2.81)	0.18 to 11.19	4.1	**<0.05**
		Intercept	-6.44 (0.21)			
		Lying density	11.98 (2.98)	6.17 to 17.80	16.3	**<0.0001**
		Intercept	-6.33 (0.20)			
		Standing density	3.79 (1.52)	0.82 to 6.76	6.2	**<0.05**
		Intercept	-6.53 (0.21)			
		Walking density	0.76 (0.14)	0.48 to 1.04	28.4	**<0.0001**



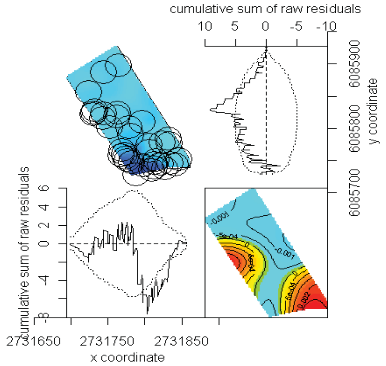
Grazing



Standing



Lying

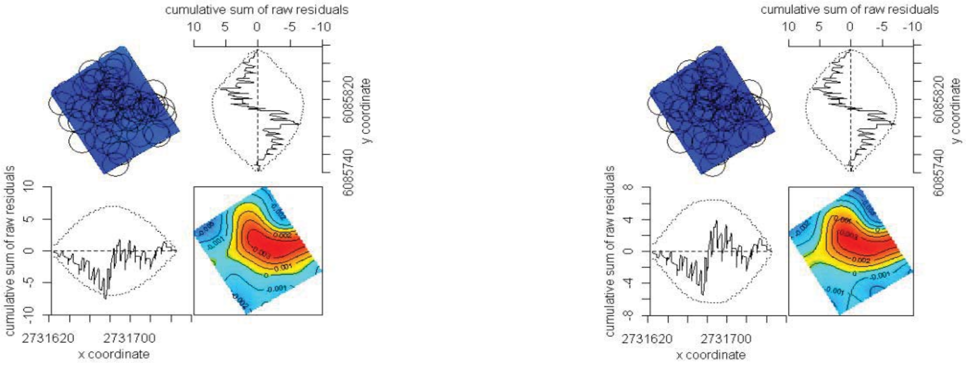


Walking

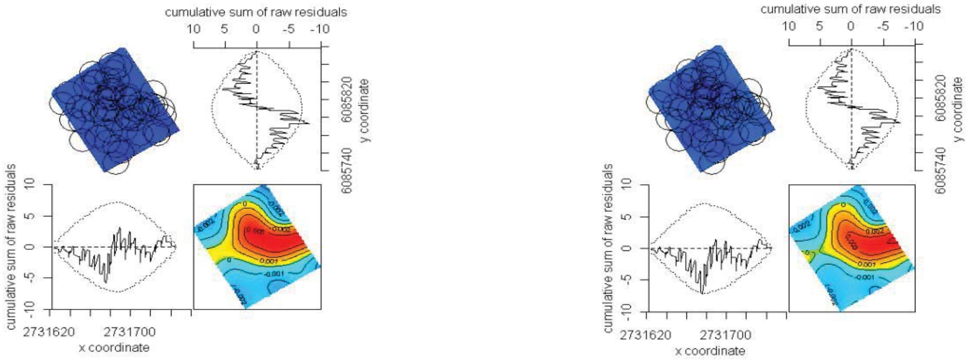
[†] PM: based on behaviour data at pasture from 20:00 until morning milking. [§] Estimate: estimated intensity function of fitted coefficients. [‡] SE: Standard error of fitted intensity. [*] CI: Confidence intervals of fitted intensity. [**] X^2: chi-squared goodness-of-fit test. Interpretation of diagnostic plots: Top left panel – circles represent data points of urine, colour scheme represents fitted intensity. Colour intensity should follow circle intensity if the model was true; bottom right panel – smoothed residual field based on kernel estimate of urine patch intensity of the fitted model. The difference should be approximately zero if the model was true; two other panels – lurking variable plots against spatial coordinates with 5% significance bands. The residual line should be within the significance bands and approximately zero if the model was true.

Table 4.12. Fitted inhomogeneous Poisson process model with estimated intensities of urine distribution which were function of the spatial covariates (Grazing, Lying, Standing and Walking), chi-squared test applied to the fitted model and residual diagnostic plots from the fitted model in paddock 61, AM1 period.

Paddock	AM/PM	Variable	Estimate[§] (SE[‡])	95% CI[*]	X^{2**}	P-value
61	AM1[†]	Intercept	-5.69 (0.49)			
		Grazing density	1.50 (1.36)	-1.16 to 4.16	1.2	>0.05
		Intercept	-5.28 (0.20)			
		Lying density	2.34 (3.36)	-4.24 to 8.93	0.49	>0.05
		Intercept	-5.06 (0.26)			
		Standing density	-2.62 (4.65)	-11.73 to 6.50	0.32	>0.05
		Intercept	-5.38 (0.20)			
		Walking density	0.48 (0.35)	-0.20 to 1.17	1.9	>0.05



Grazing Standing

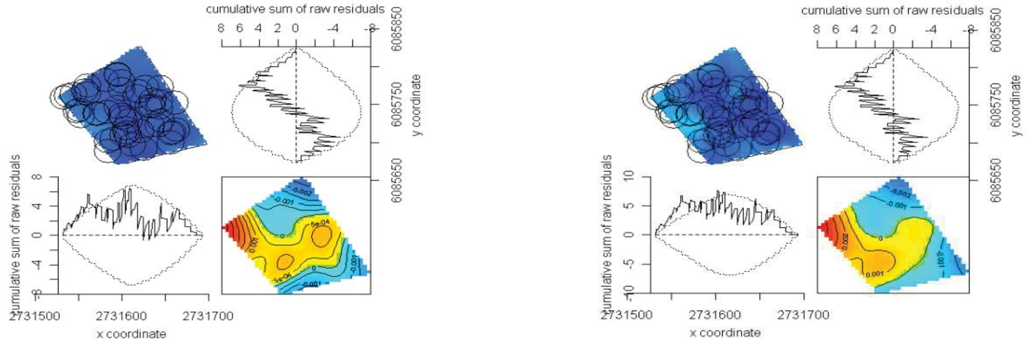


Lying Walking

[†]AM: based on behaviour data at pasture between morning and afternoon milking. [§]Estimate: estimated intensity function of fitted coefficients. [‡]SE: Standard error of fitted intensity. [*]CI: Confidence intervals of fitted intensity. [**]X^2: chi-squared goodness-of-fit test. Interpretation of diagnostic plots: Top left panel – circles represent data points of urine, colour scheme represents fitted intensity. Colour intensity should follow circle intensity if the model was true; bottom right panel – smoothed residual field based on kernel estimate of urine patch intensity of the fitted model. The difference should be approximately zero if the model was true; two other panels – lurking variable plots against spatial coordinates with 5% significance bands. The residual line should be within the significance bands and approximately zero if the model was true.

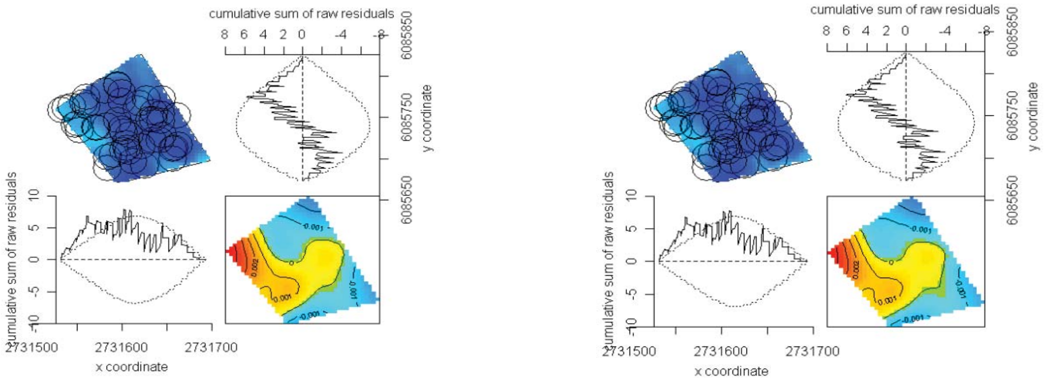
Table 4.13a. Fitted inhomogeneous Poisson process model with estimated intensities of urine distribution which were function of the spatial covariates (Grazing, Lying, Standing and Walking), chi-squared test applied to the fitted model and residual diagnostic plots from the fitted model in paddock 62, AM2 period.

Paddock	AM/PM	Variable	Estimate (SE[‡])	95% CI[*]	X^{2}[**]	P-value
62	AM2[†]	Intercept	-5.88 (0.41)			
		Grazing density	0.70 (1.48)	-2.20 to 3.60	0.22	>0.05
		Intercept	-5.72 (0.19)			
		Lying density	5.26 (29.25)	-52.07 to 62.58	0.032	>0.05
		Intercept	-5.79 (0.21)			
		Standing density	1.87 (2.96)	-3.93 to 7.66	0.4	>0.05
		Intercept	-5.72 (0.15)			
		Walking density	1.22 (3.38)	-5.39 to 7.84	0.13	>0.05



Grazing

Standing



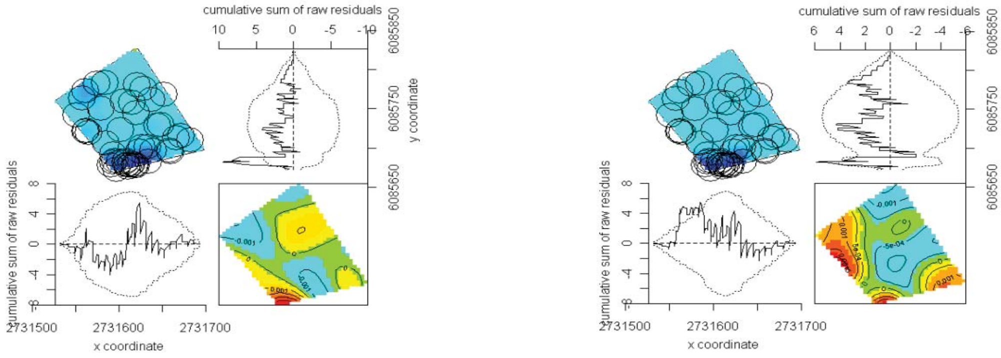
Lying

Walking

[†] AM: based on behaviour data at pasture from afternoon milking until 20:00. [‡§] Estimate: estimated intensity function of fitted coefficients. [‡] SE: Standard error of fitted intensity. [*] CI: Confidence intervals of fitted intensity. [**] X^{2}: chi-squared goodness-of-fit test. Interpretation of diagnostic plots: Top left panel – circles represent data points of urine, colour scheme represents fitted intensity. Colour intensity should follow circle intensity if the model was true; bottom right panel – smoothed residual field based on kernel estimate of urine patch intensity of the fitted model. The difference should be approximately zero if the model was true; two other panels – lurking variable plots against spatial coordinates with 5% significance bands. The residual line should be within the significance bands and approximately zero if the model was true.

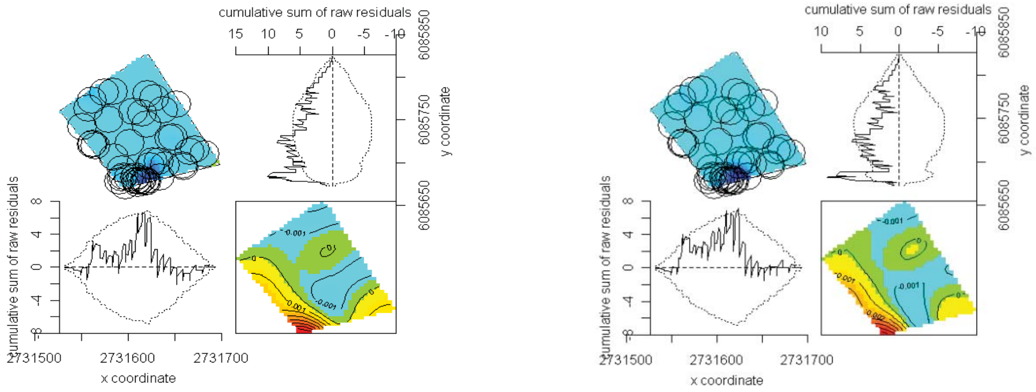
Table 4.13b. Fitted inhomogeneous Poisson process model with estimated intensities of urine distribution which were function of the spatial covariates (Grazing, Lying, Standing and Walking), chi-squared test applied to the fitted model and residual diagnostic plots from the fitted model in paddock 62, PM period.

Paddock	AM/PM	Variable	Estimate (SE[‡])	95% CI[*]	X^{2**}	P-value
62	PM[†]	Intercept	-6.77 (0.24)			
		Grazing density	8.75 (1.13)	6.53 to 10.96	60.0	**<0.0001**
		Intercept	-6.44 (0.21)			
		Lying density	20.05 (2.54)	15.08 to 25.02	62.5	**<0.0001**
		Intercept	-6.35 (0.20)			
		Standing density	3.90 (0.41)	3.10 to 4.70	91.6	**<0.0001**
		Intercept	-6.34 (0.20)			
		Walking density	0.90 (0.11)	0.69 to 1.10	72.2	**<0.0001**



Grazing

Standing



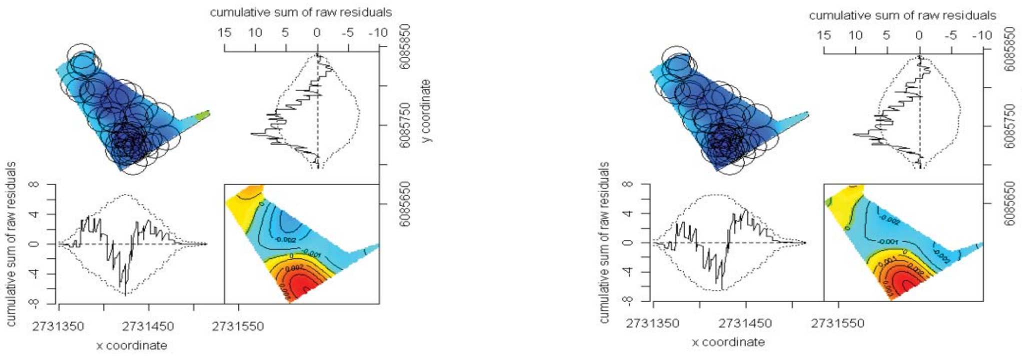
Lying

Walking

[†]PM: based on behaviour data at pasture from 20:00 until morning milking. [‡§]Estimate: estimated intensity function of fitted coefficients. [‡]SE: Standard error of fitted intensity. [*]CI: Confidence intervals of fitted intensity. [**]X^2: chi-squared goodness-of-fit test. Interpretation of diagnostic plots: Top left panel – circles represent data points of urine, colour scheme represents fitted intensity. Colour intensity should follow circle intensity if the model was true; bottom right panel – smoothed residual field based on kernel estimate of urine patch intensity of the fitted model. The difference should be approximately zero if the model was true; two other panels – lurking variable plots against spatial coordinates with 5% significance bands. The residual line should be within the significance bands and approximately zero if the model was true.

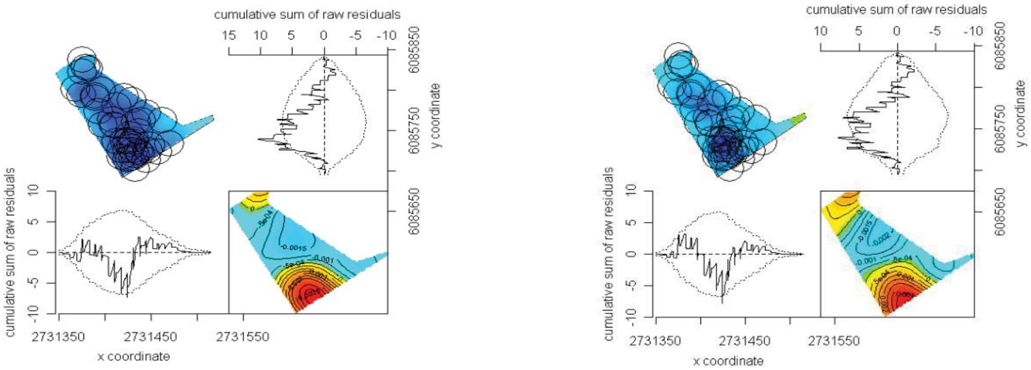
Table 4.14a. Fitted inhomogeneous Poisson process model with estimated intensities of urine distribution which were function of the spatial covariates (Grazing, Lying, Standing and Walking), chi-squared test applied to the fitted model and residual diagnostic plots from the fitted model in paddock 78, AM2 period.

Paddock	AM/PM	Variable	Estimate (SE[‡])	95% CI[*]	X^2[**]	P-value
78	AM2[†]	Intercept	-7.03 (0.50)			
		Grazing density	4.41 (1.11)	2.23 to 6.58	15.7	**<0.0001**
		Intercept	-5.20 (0.21)			
		Lying density	-15.56 (18.74)	-52.29 to 21.18	0.69	>0.05
		Intercept	-5.48 (0.24)			
		Standing density	1.84 (2.10)	-2.81 to 5.68	0.77	>0.05
		Intercept	-5.73 (0.18)			
		Walking density	4.16 (0.74)	2.70 to 5.61	31.3	**<0.0001**



Grazing

Standing



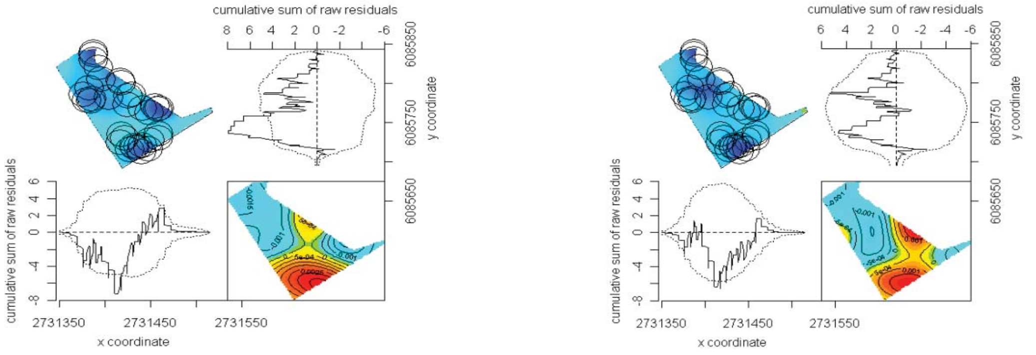
Lying

Walking

[†]AM: based on behaviour data at pasture from afternoon milking until 20:00. [‡]Estimate: estimated intensity function of fitted coefficients. [‡]SE: Standard error of fitted intensity. [*]CI: Confidence intervals of fitted intensity. [**]X^2: chi-squared goodness-of-fit test. Interpretation of diagnostic plots: Top left panel – circles represent data points of urine, colour scheme represents fitted intensity. Colour intensity should follow circle intensity if the model was true; bottom right panel – smoothed residual field based on kernel estimate of urine patch intensity of the fitted model. The difference should be approximately zero if the model was true; two other panels – lurking variable plots against spatial coordinates with 5% significance bands. The residual line should be within the significance bands and approximately zero if the model was true.

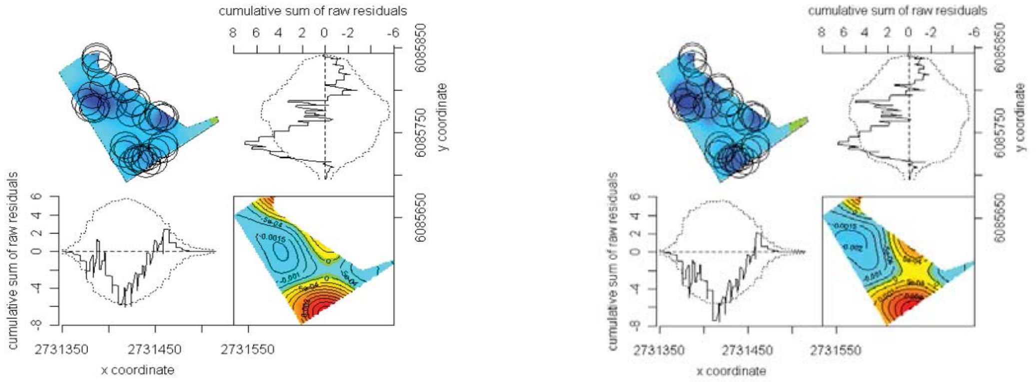
Table 4.14b. Fitted inhomogeneous Poisson process model with estimated intensities of urine distribution which were function of the spatial covariates (Grazing, Lying, Standing and Walking), chi-squared test applied to the fitted model and residual diagnostic plots from the fitted model in paddock 78, PM period.

Paddock	AM/PM	Variable	Estimate (SE[‡])	95% CI[*]	X^{2**}	P-value
78	PM[†]	Intercept	-6.08 (0.25)			
		Grazing density	3.80 (1.38)	1.10 to 6.49	7.6	**<0.01**
		Intercept	-6.09 (0.23)			
		Lying density	9.33 (2.08)	5.25 to 13.41	20.1	**<0.0001**
		Intercept	-6.22 (0.23)			
		Standing density	3.22 (0.57)	2.10 to 4.35	31.5	**<0.0001**
		Intercept	-6.36 (0.26)			
		Walking density	0.69 (0.13)	0.42 to 0.95	26.3	**<0.0001**



Grazing

Standing



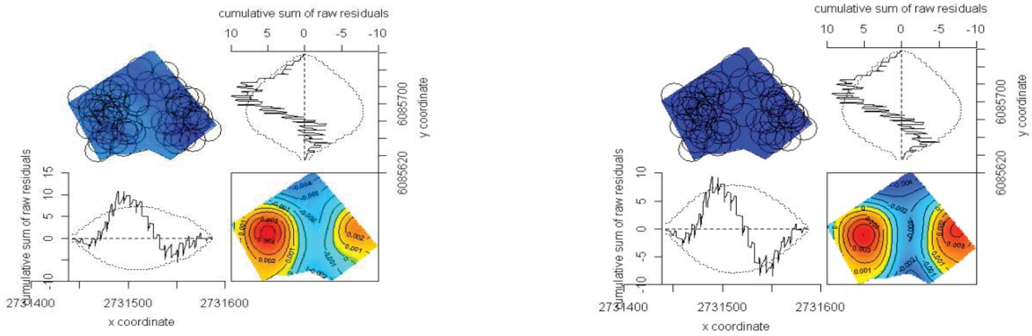
Lying

Walking

[†]PM: based on behaviour data at pasture from 20:00 until morning milking. [‡]Estimate: estimated intensity function of fitted coefficients. [‡]SE: Standard error of fitted intensity. [*]CI: Confidence intervals of fitted intensity. [**]X^2: chi-squared goodness-of-fit test. Interpretation of diagnostic plots: Top left panel – circles represent data points of urine, colour scheme represents fitted intensity. Colour intensity should follow circle intensity if the model was true; bottom right panel – smoothed residual field based on kernel estimate of urine patch intensity of the fitted model. The difference should be approximately zero if the model was true; two other panels – lurking variable plots against spatial coordinates with 5% significance bands. The residual line should be within the significance bands and approximately zero if the model was true.

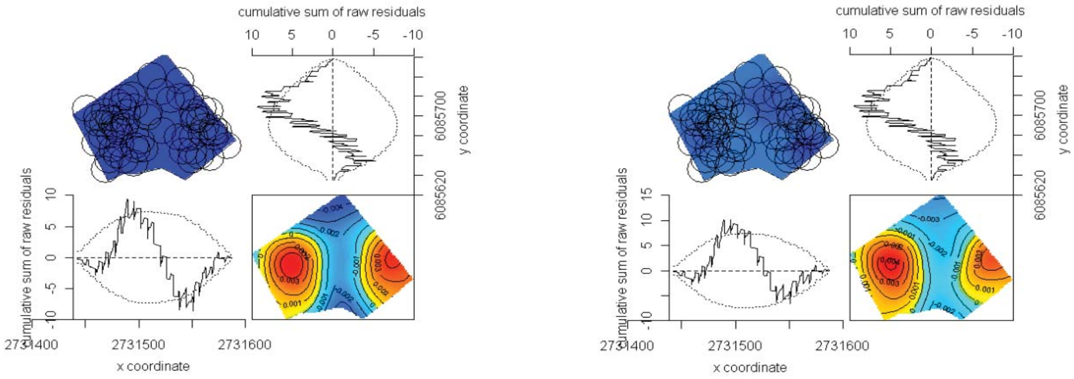
Table 4.15. Fitted inhomogeneous Poisson process model with estimated intensities of urine distribution which were function of the spatial covariates (Grazing, Lying, Standing and Walking), chi-squared test applied to the fitted model and residual diagnostic plots from the fitted model in paddock 79, AM1 period.

Paddock	AM/PM	Variable	Estimate[§] (SE[‡])	95% CI[*]	X^{2**}	P-value
79	AM1[†]	Intercept	-5.74 (0.32)			
		Grazing density	1.62 (0.84)	-0.02 to 3.26	3.7	**<0.05**
		Intercept	-5.19 (0.17)			
		Lying density	-0.39 (4.23)	-8.68 to 7.91	0.0083	>0.05
		Intercept	-5.23 (0.19)			
		Standing density	0.39 (1.95)	-3.43 to 4.20	0.04	>0.05
		Intercept	-5.35 (0.16)			
		Walking density	0.45 (0.26)	-0.07 to 0.97	2.9	>0.05



Grazing

Standing



Lying

Walking

[†] AM: based on behaviour data at pasture between morning and afternoon milking. [‡] Estimate: estimated intensity function of fitted coefficients. [‡] SE: Standard error of fitted intensity. [*] CI: Confidence intervals of fitted intensity. [**] X^2: chi-squared goodness-of-fit test. Interpretation of diagnostic plots: Top left panel – circles represent data points of urine, colour scheme represents fitted intensity. Colour intensity should follow circle intensity if the model was true; bottom right panel – smoothed residual field based on kernel estimate of urine patch intensity of the fitted model. The difference should be approximately zero if the model was true; two other panels – lurking variable plots against spatial coordinates with 5% significance bands. The residual line should be within the significance bands and approximately zero if the model was true.

4.4. Discussion

There were weak to moderate associations between urine patch density and the density of each of the behaviour variables used in this study. The most consistent and strong associations were observed between the urine patch density and densities of standing and lying behaviour (where a lag factor of +2 min was applied, see Section 4.2.2.) in the PM period. Grazing density correlations were weaker than that of standing and lying behaviour and showed more consistency between paddocks for the AM1 and PM periods compared with patterns in the AM2 period. The frequency of lying behaviour was also highest during the PM period with lying being the predominate behaviour between 20:00 h and morning milking (Chapter 3). Lying and standing behaviours followed similar distribution patterns and followed a pronounced non-uniform density outline. Grazing behaviour, on the other hand, although significantly non-random in its distribution, was the behaviour with most uniform density within paddocks (Chapter 3). Cows tended to graze throughout all areas of paddocks, while areas associated with standing and lying tended to be smaller and occupied for longer than any area used for grazing. Furthermore, the associations found between lying and standing density and the density of urination patches may be more consistent to that of grazing density because IceTag3D®s were found to measure standing and lying behaviours more accurately than locomotion (Trenel *et al.,* 2009). Therefore, associations between urine patch density and behaviour density were more likely to be detected when both urination and behaviour are concentrated in a relatively smaller area over longer time frames, and when using IceTag3D® devices. The localised aggregation of standing and lying cows, particularly during the PM period, would likely result in high N losses due to the potential of urine patch overlap and the consequent exponential rise in the rate of N leaching (Pleasant et al., 2007; McGechan and Topp, 2004) and nitrous oxide emissions (Di and Cameron, 2003).

It is important to note, however, that results in this study should be interpreted with caution because there were variations in dominant behaviours between paddocks and although results were significant, correlation coefficients were weak in general. Further studies are needed to contribute to building a clearer picture of the association between behaviour density and density of urine patches over longer time periods. This will take into account the effects of factors such as season (Rook and Huckle, 1996; Hessle *et al.*, 2007; Webster *et al.*, 2008), management (Orr *et al.*, 2001; Dalley *et al.*, 2001), stage of lactation (Chaplin and Munksgaard, 2001) and stocking density (Stockdale and King, 1983) on behaviour and possible subsequent effects on urine patch density.

Fitting urine patch data with a distribution that is a function of the density of a particular behaviour variable was possible, although patterns were inconsistent. Time of day had a significant effect on the fit of the model with behaviour variables being better predictors of urine patch distribution during night hours (PM period) than during day-light hours (AM1 and AM2 periods). There was similarity in the patterns between the results of the PPM and that of the relationship linking the density of behaviour variables with urine patch density. For example, urine patch distribution could not be fitted as a function of any behaviour variable for all paddocks that did not show clear associations between behaviour density and the density of urine patches (paddocks 61, 62 [AM2 period only] and 79). This is to be expected as the model is based on the actual point pattern dataset of urine patches and the density of each behaviour variable.

Some of the inconsistencies in the PPM may be due to the small sample size where information from only one grazing per paddock was used to generate data for the model. The correlation coefficients of each behaviour variable were also relatively small, implying that variables explained only a small amount of the variance in the data. Thus, these behaviour variables were not the most suitable indirect indicator of where the cows urinate in this study. Further studies are needed to generate more data because the PPM is significantly affected by small-sample bias (Baddeley and Turner, 2005). However, the PPM is the most general and flexible model for fitting point process models to be found at present. There are other numerical approximation methods (Ogata and Tanemura, 1986; Geyer and Moller, 1994) available that are highly specific to the chosen model and require careful tuning to ensure good performance. For example, Markov chain Monte Carlo methods are computationally intensive, especially for inhomogeneous spatial patterns (Baddeley and Turner, 2005). The PPM is extremely fast in execution, but should be regarded as tentative, especially when using data with a relatively small sample size.

4.5. Conclusions

1. The use of behaviour density data as a predictor of urine patch distribution showed promise, but in this study was not definitive. The model used here was preliminary and tested the potential of using behaviour data to model urine patch distribution. Although there were some encouraging results, further studies are needed to investigate the effects of grazing, lying, standing and walking on urine patch distribution over longer time frames.

Modelling animal behaviour and nutrient distribution is a complex task because there are many significant factors and interactions that may impact behaviour. Trying to include the majority of factors and interactions has negative consequences for model complexity and runtime. There is a need to attempt to reduce the associated complexities by reducing the number of significant variables. Resulting quantitative predictions are necessarily incomplete, but are often less ambiguous and easier to test. The modelling of the spatial distribution of urine patches using behavioural variables is showing promise, but needs to be tested over longer time frames and in a wider range of settings.

Chapter Five: General Discussion, Conclusions and Recommendations

5.1. Major findings

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 N pollution arising from dairy farms due to the inhomogeneous nature of bovine urine patches. The non-uniform distribution of urine on paddocks can lead to higher N losses into water courses due to the consequent exponential rise in the rate of N leaching and the over-fertilisation of areas already rich in excreta with N fertiliser. Several factors influence the distribution of nutrients by livestock through the effects of these on the behaviour of individual dairy cows or groups.

The general aim of this thesis was to investigate the use of emerging sensor and precision tracking technologies to study and track dairy cows managed under commercial conditions. The study also aimed to provide baseline knowledge on the distribution of urine by dairy cows in regard to environmental, management and behaviour factors. The studies in this thesis show that the use of urine sensors, GPS tracking units and IceTag3D® motion sensors were effective for capturing data on the temporal and spatial behaviour of dairy cows in a commercial herd. Urine deposition and grazing, lying, standing and walking behaviours were non-random as seen by the aggregation of urine patches and particular behaviour activities within highly stocked and relatively flat grazed paddocks.

A methodology suitable for observing the behaviour of dairy cows managed in large groups on pasture under commercial conditions was developed over three trials, thereafter the effects of temporal and environmental factors on urination behaviour was described (Chapter Two). The urination behaviour results were similar to visual observations reported in the literature indicating that the remote sensing methods used to gather urination data show great potential when deployed in a commercial dairy herd. The majority of urine (85% of total) was deposited on pasture, while 10% of total urine deposits were captured in the holding yard and 5 % in the milking shed. 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. Paddocks used in this study had sufficient pasture mass and were relatively flat, which provided adequate area for foraging and resting without the need to explore steeper areas or search for areas with high pasture mass. In contrast to set-stock management for example, dairy cows are in a paddock for a relatively short period 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.

The interactions between activity patterns, environmental factors and urination behaviour of dairy cows were investigated in the study and were described in Chapter Three. Activity patterns were comparable to those reported for cows in other studies managed both in small and large groups, indicating that the IceTag3D® methods used to monitor the behaviour of dairy cows provided reliable data. The dairy cows were observed to have distinctive time budgets. The times of sunset and sunrise, and the removal of cows for milking, were the main factors influencing activity patterns of animals in this study. Significant correlations between the frequencies of urination and grazing and lying behaviour followed similar temporal patterns. There was a positive relationship between urination and grazing behaviour, while the frequency of urination decreased with an increase in lying behaviour. This is to be expected as cows are unable to urinate while lying down, while grazing takes up the largest proportion of the dairy cows' activity budget and the time spent grazing is likely to also be the time cows have most opportunity to urinate. Grazing, lying, standing and walking behaviours followed inhomogeneous density patterns indicating that paddocks were not utilised at random, but different behaviours were more likely to occur in specific areas within paddocks. The density of grazing behaviour followed a more uniform pattern within paddocks than resting and lying behaviour density. It was unclear, however, what paddock characteristics influence behaviour density as specific patterns could not be attributed to a particular characteristic (e.g. elevation, aspect, slope, pasture mass) with any certainty due to substantial variations in results between paddocks. It is likely that paddock characteristics are less important in determining behaviour density when paddocks are relatively flat and highly stocked, and there is sufficient forage for dairy cows allocated fresh grazing twice a day. However, factors such as shelter and well drained areas of a paddock may have a significant impact on behaviour at different times of the year and need to be investigated further. Examination of the spatial density patterns of behaviour and urine patches indicate that there may be some association between urination and standing, and lying behaviours as these overlap within paddocks. There is a greater probability of urine patch overlap within the smaller resting areas than within grazing areas which tend to be larger. The overlap of urine patches leads to exponential increase of N concentrations (Pleasants *et al.*, 2007) and in times of slow plant uptake or under certain weather conditions can leach into the soils and waterways (White *et al.*, 2006).

In Chapter Four, the possibility of modelling urine patch distribution, using behaviour density data as a predictor of urine distribution, was investigated. Findings indicate that there was some degree of association between the spatial density patterns of behaviour and urine patches, with time of day influencing the levels of association. In particular, moderate correlations between the densities of urine patches and lying, and standing behaviours, between 20:00 h and the next day morning milking, suggest that these behaviours occur in comparable areas within paddocks in the time period. Fitting urine patch distribution data using a function of the density of a particular behaviour variable was possible, although the correlation coefficients of each behaviour variable were small, implying that variables explained only a small amount of the data variance. It appears that the behaviour variables were not the most suitable indirect indicator of where the cows urinate in this study. Although results from the PPM were inconclusive, the model as such provided flexibility and a fast execution when fitting point process data.

5.2. Limitations and improvements

A major weakness of this thesis was the limited data available despite an extensive development and a planning stage prior and during each trial. As mentioned earlier, the first trial (March 2008) was cancelled due to drought, while equipment failure hindered the retrieval of data from the following two trials (November 2008 and January 2009). This led to data being available from only one trial on which to base the studies for this thesis. Urine sensors were particularly unreliable. Many sensors fell off the cows and were lost in paddocks, while some simply did not log data. Global positioning system units and to a lesser extent IceTag3D®s performed well with only minor faults being detected. Measurements carried out by a third party also hindered retrieving reliable pasture mass data from the Rapid Pasture Meter® in the November 2008, January and March 2009 trials. Although pasture mass was measured pre and post-grazing, data was deemed reliable only for the pre-grazing period, which was mainly due to operator errors. The farm staff were then asked to provide post-grazing pasture mass estimate instead. This may be why the post-grazing pasture mass is somewhat low for grazing lactating cows. Even though problems with equipment led to fewer data being collected than expected, operator errors led to an understanding of how to improve tracking and sensor tools in ways that are suitable to use on dairy cows under a commercial setting.

GPS units

GPS units worked well in all trials. One unit failed due to water entering into the plastic casing. Extra care should be taken to waterproof the GPS unit casings after installing new batteries. GPS unit can be made sufficiently waterproofed by tightening casing bolts and where needed applying silicon filler to stop water entering the unit through any gaps.

Urine sensors

Urine sensors were the most problematic of all sensor tools. The two major problems encountered were the ‘flooding’ of the data storage area of the sensor and the loss of sensors where they fell off cows.

Some sensors were ‘flooded’ by vaginal fluids which corrupted data recording and retrieval of any data already stored on the sensor by compromising the electronic circuit board. The fluids entered the area of the circuit board where the modified CIDR® device was connected to the silicon tube (Plate 2.3., Chapter 2). In order to waterproof the area silicon tape was applied at the time of sealing the electronic circuit board compartment. Following that, sensors were submerged in a bucket of water to verify that the electronic circuit compartment was made waterproof. These steps were sufficient to prevent any future problems with ‘flooding’ of the sensors.

The loss of urine sensors where they fell off cows was most likely due to several factors. Firstly, it was observed that when cows lie down the silicon tube ends up wedged under the hind legs. The motion involved in getting up is such that the hind legs are last to leave the ground and can trap the tube and pull it out of the cow in the process. Although the silicon tube was shortened, it still had to cover the cable with the thermistor which may not have been enough to remedy the problem completely. Secondly, it was observed that several urine sensors fell off cows while they were kept in the holding yard prior to entering the milking platform. Cows where ‘pushed’ forward by a backing gate in order to encourage them to move towards the milking platform. In this situation cows were in close proximity to each other and there was a lot of movement where cows pushed one another. The silicon tube of the sensor can get trapped between two cows and can be pulled out in the process. The use of the backing gate was stopped for the duration of the study which greatly improved urine sensor retention; in fact no more urine sensors fell out of cows in the holding yard.

Data analysis

Although the tracking and sensor tools used in this study are particular useful in gathering data from large groups of animals kept under commercial conditions, these tools also generate large data sets. Such data sets take considerable time to manipulate and made ready for statistical analysis. There are no ready methodological protocols available at present to deal with large and complex data sets from multiple tracking and sensor tools, therefore data analysis from such studies take considerable amount of time, something that should be taken into account in future studies. The development of methodological protocols in the future will help immensely with the management of large data sets generated by tracking and sensor tools.

5.3. Conclusions

It is concluded that a suitable methodology was developed to observe, track and analyse the behaviour of dairy cows managed on pasture under commercial conditions using tracking and sensor technologies. Dairy cows, managed under commercial conditions on relatively flat land in early autumn, were found to deposit the majority of their urine on pasture, where urine patches were found to have a non-random distribution. The activity patterns of these dairy cows were mainly influenced by the time of day and management practices such as removing cows from pasture for milking.

Dairy cows at pasture were observed to aggregate in resting areas, while grazing followed a more uniform pattern. Although the frequencies of urination and grazing behaviour followed similar temporal patterns, the spatial density patterns of grazing and urine patches indicate that there may be some association between urination and standing, and lying behaviours. Furthermore, although urination frequencies were low during times spent lying, any urination during times of rest may lead to an exponential increase in N losses and emissions, than urination during grazing, due to the greater probability of patch overlap within the smaller resting areas. This would apply especially to steeper contoured land where the proportion of flat land that is the preferred resting areas is small.

Using behaviour parameters to predict urine deposits with any certainty was not possible in this study. Although the PPM was the most general and flexible model for fitting point process data found at present, it can be negatively affected by small sample sizes.

5.4. Practical recommendations and future research

The methodologies developed in this thesis provide useful tools to investigate the effects of environmental and management factors on the behaviour of a range of livestock species, including grazing dairy cows. Knowledge of how animal behaviour is influenced by management decisions and the environment is important in considering current systems of management and also in evaluating new management routines, with the aim of improving productivity and farm profitability. Thus, future research could utilise this methodology to evaluate both current and new management systems.

The results of this study clearly demonstrate that for grazing dairy cows the majority of urine is deposited on pasture. Findings indicate that urine patches tend to be more aggregated during times of rest rather than during grazing, specifically between sunset and morning milking. Areas where there is an aggregation of urine patches will have higher rates of N leaching than the average for the paddock because a) N concentration increases when urine patches overlap and b) fertilisers are commonly spread uniformly across a paddock contributing to N loads in areas that already have levels of N in excess of what plants can use in a year. These can have a negative environmental impact because N in excess to plant requirements is nitrified to nitrate, which is easily leached in the following drainage season to ground and surface waters.

This study shows that if dairy cows are kept off pasture on a standoff area between sunset and morning milking, 29% of total urine patches can be removed from pasture. If cows are also to be kept away from pasture between 10:00 and afternoon milking (another period of rest) a further 21% of total urine parches can be removed without markedly impacting pasture intake. It is important to point out however, that the morning rest period is less defined and the effects of restricted grazing, in the morning, needs further investigation in order to ensure that the welfare and productivity of cows is not compromised. If there are to be two standoff periods, dairy cows will be able to graze for four hours in the morning and five hours in the afternoon. However, times of sunrise and sunset will change with seasons and these, together with lactation stage, are likely to have an effect on the behaviour of cows and on the time spent off pasture. Further studies need to examine how the change in seasons affects grazing and resting behaviour and adjust standoff time accordingly so grass intake is not compromised. By having two standoff periods 60% of total urine deposits (including 10% already deposited in holding yard and milking shed) can be captured and applied across paddocks in a more uniform manner as needed.

Although the effects of standoff time on the rate of N leaching was not investigated here, additional studies could determine the actual reduction of N losses to the environment when dairy cows are kept away from pasture for particular periods of the day. While there may be several options available to farmers to reduce N losses to the environment, the mechanisms by which time away from pasture affects some aspects of changes to cow behaviour, welfare and productivity are unclear. Therefore, while simple recommendations can be provided on ways to reduce the amount of N leached into the environment, further work is required to determine the important factors by which time off pasture impacts on cow behaviour, welfare and productivity. Thus definitive recommendations cannot be made until such work has been completed.

Further studies are needed to contribute to building a clearer picture of the association between behaviour density and density of urine patches over longer time periods (e.g. repeat observations at later grazings of the same paddocks), and validating the effects that were explored in this study Such studies will take into account the effects of factors such as season and stage of lactation on behaviour and possible subsequent effects on urine patch density.

Utilising the methods developed within this thesis, more research can be completed on flat, rolling and steep commercial dairy farms, under different stocking densities, pastoral availability and management scenarios before firm conclusions can be drawn, so that a clearer understanding of nutrient distribution by the grazing dairy cow can be determined. Such understanding will allow farmers and fertiliser consultants to better match nutrient needs and placement of fertiliser at the within-paddock scale to optimise returns from money invested in their enterprises.

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Appendices

APPENDIX I (Chapter Two)

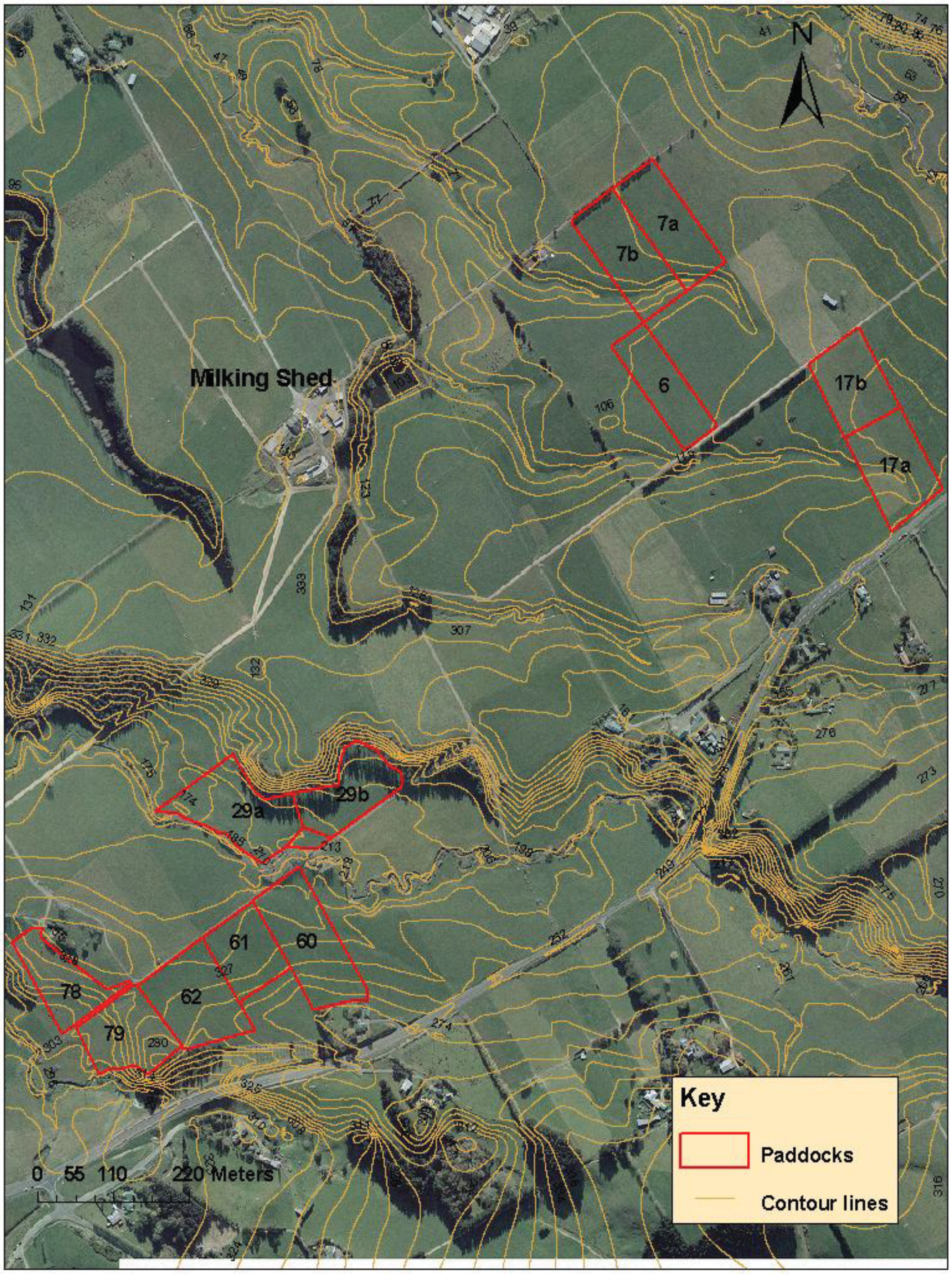


Plate A1. Aerial view of Massey University Dairy No.4, including paddocks used in the present study, milking shed and contour lines for the area.

Table A1. Summary of planned trials outlining the length of each study together with the tracking and sensor equipment used, and the experimental outcome.

Trial	Length of study[†]	GPS[*] units	Urine sensors[§]	IceTag3D®[‡]	Rapid Pasture Meter®[#]	Experimental outcome
March 2008	Cancelled	NA	NA	NA	NA	NA
November 2008	3rd - 17th	30 units deployed	20 sensors deployed	None deployed	pre-and post grazing pasture mass measures carried out for 12 paddocks	Unsatisfactory: Technical difficulties with equipment. Urine sensors and the Rapid Pasture Meter failing to log data on numerous occasions.
January 2009	12th - 26th	30 units deployed	22 sensors deployed	20 sensors deployed	pre-and post grazing pasture mass measures carried out for 12 paddocks	Unsatisfactory: Technical difficulties with equipment, data retrieval and third party pasture measurements.
March 2009	9th – 23rd	30 units deployed	24 sensors deployed	17 sensors deployed	pre-and post grazing pasture mass measures carried out for 12 paddocks	Satisfactory: Data from 15 urine sensors, 29 GPS units and 17 IceTag3D®s considered reliable. Pasture measurements less successful, only pre-grazing measurements for 8 paddocks deemed reliable.

[†] Dates include time allocation for the investigation of the milking order of the herd prior to the deployment of the tracking and sensor equipment.

[*] Global Positioning System. Data from the units was used to determine the location of individual cows in space and time.

[§] Detects urination events. Data from urine sensor was used in conjunction with GPS data to generate approximate location of urination events.

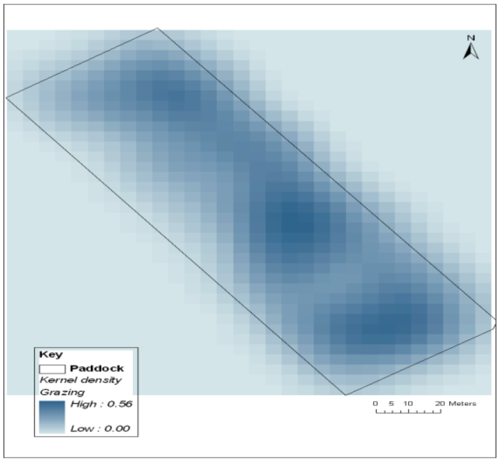
[‡] The IceTag3D® is an activity monitor that uses accelerometer technology to determine the proportion of time an animal is lying, standing or active.

[#] The Rapid Pasture Meter® sensor output was used to create a measure of pasture mass (kg DM/ha) for each paddock in the study.

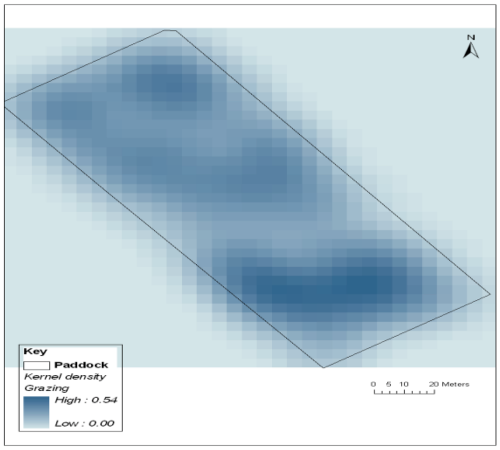
APPENDIX II (Chapter Three)

Table A2. Mean % of time spend in each behaviour per hour and standard deviation (SD) of 17 dairy cows over seven consecutive days.

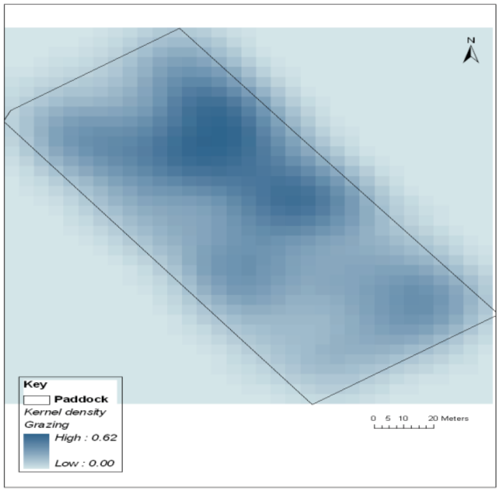
Hour	Grazing	SD	Lying	SD	Standing	SD	Walking	SD
5:00	0	0.0	0	0.0	74	8.1	26	4.0
6:00	87	9.2	0	0.0	8	8.2	6	4.5
7:00	83	10.0	3	4.3	12	8.2	2	1.4
8:00	44	18.2	42	21.3	13	7.3	1	0.9
9:00	28	15.7	63	19.5	8	5.6	1	1.3
10:00	52	14.3	30	17.3	15	8.0	3	1.4
11:00	44	8.4	26	9.5	28	7.4	2	1.5
12:00	33	11.7	41	9.8	24	9.4	2	1.1
13:00	34	5.4	18	8.3	11	3.5	36	7.8
14:00	0	0.0	0	0.0	71	7.6	29	7.0
15:00	84	8.0	0	0.7	4	4.1	12	7.0
16:00	88	5.9	4	4.9	6	5.5	2	1.3
17:00	83	7.5	6	5.6	10	7.5	2	1.5
18:00	72	12.9	7	8.8	19	8.9	1	1.1
19:00	47	13.1	21	15.6	31	10.5	1	0.9
20:00	6	3.8	80	12.8	14	9.8	0	0.4
21:00	10	8.5	77	14.5	13	9.8	0	0.4
22:00	19	10.7	72	11.4	8	6.9	0	0.9
23:00	25	11.7	56	15.0	17	7.4	1	1.3
0:00	13	6.2	69	11.9	17	8.7	0	0.4
1:00	7	4.8	79	11.3	13	8.8	0	0.4
2:00	5	3.5	83	9.7	12	7.6	0	0.4
3:00	1	1.0	95	4.9	3	4.4	0	0.1
4:00	14	5.6	28	13.7	12	7.9	46	2.0



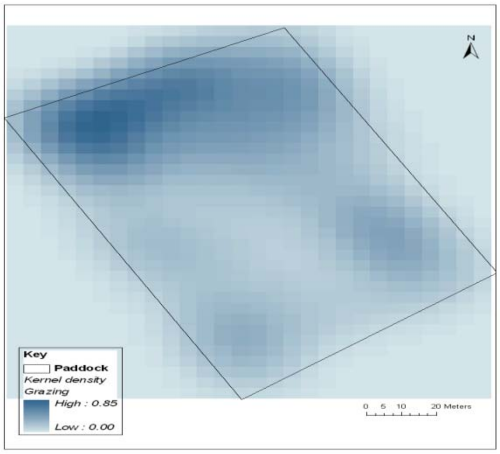
a) Paddock 6



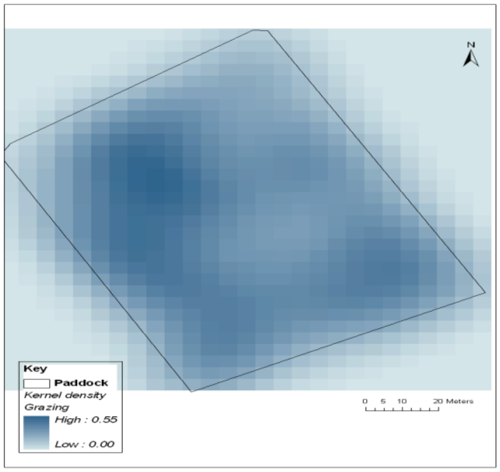
b) Paddock 7a



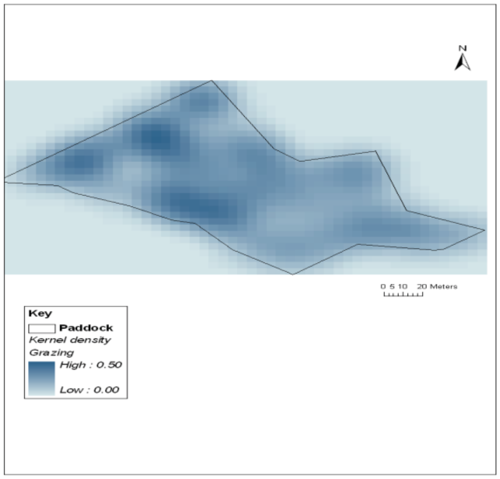
c) Paddock 7b



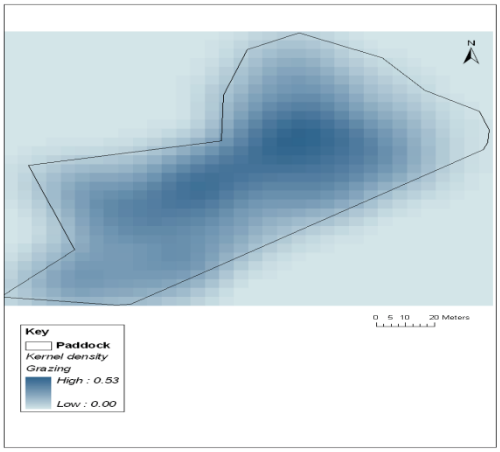
d) Paddock 17a



e) Paddock 17b



f) Paddock 29a



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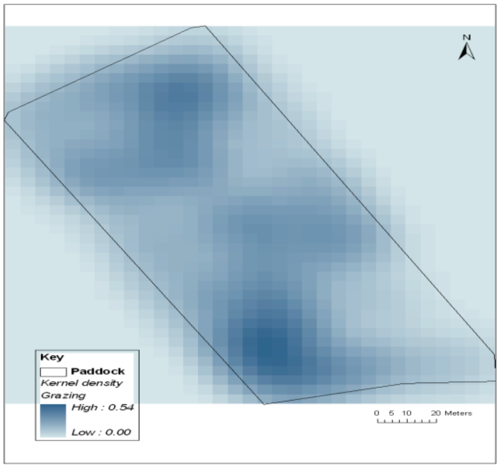
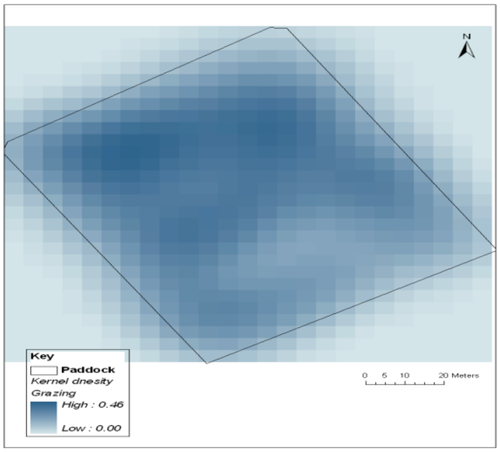
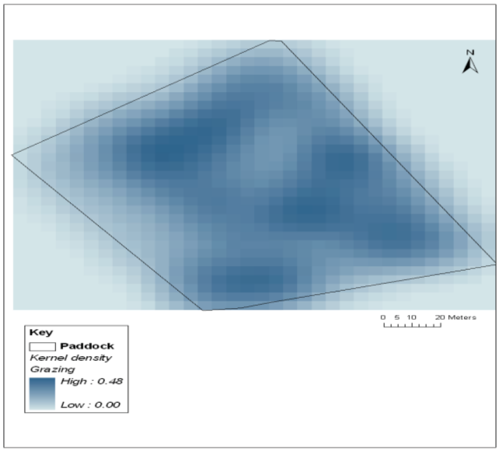


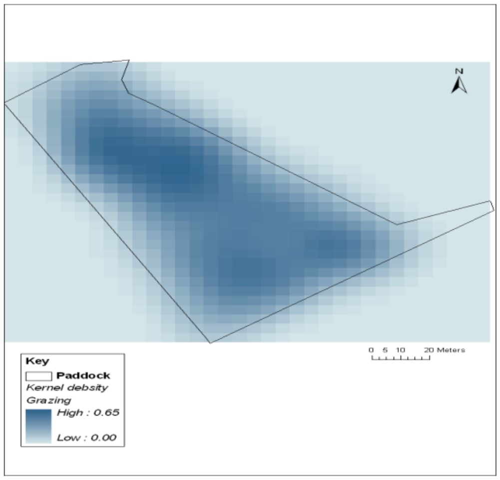
h) Paddock 60



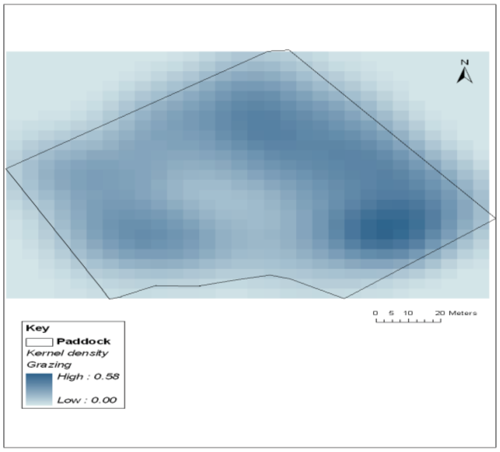
i) Paddock 61



j) Paddock 62

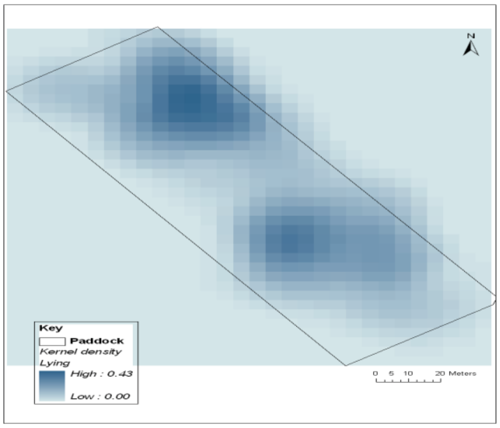


k) Paddock 78

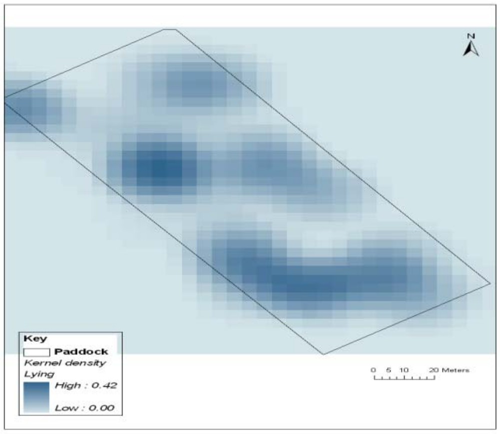


l) Paddock 79

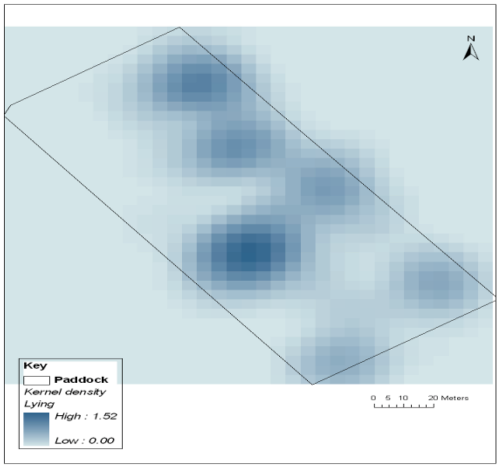
Figure A1. Kernel density estimates of grazing behaviour based on a 5m x 5m cell grid for each paddock.



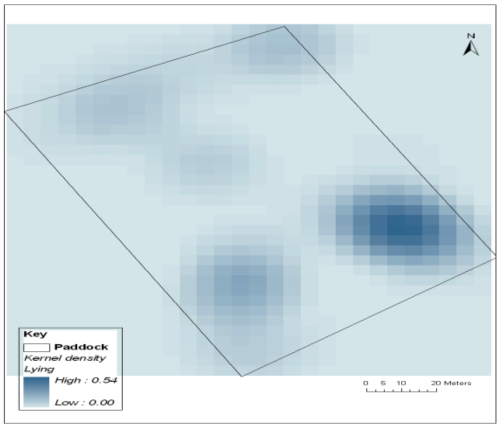
a) Paddock 6



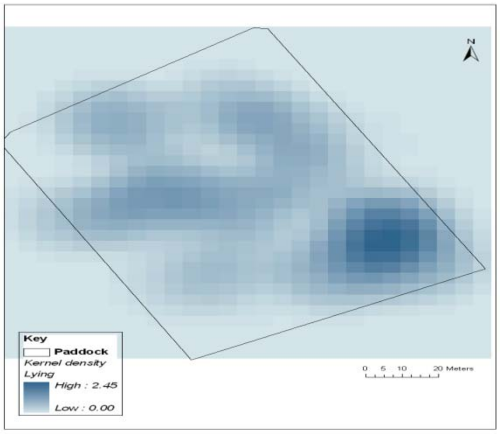
b) Paddock 7a



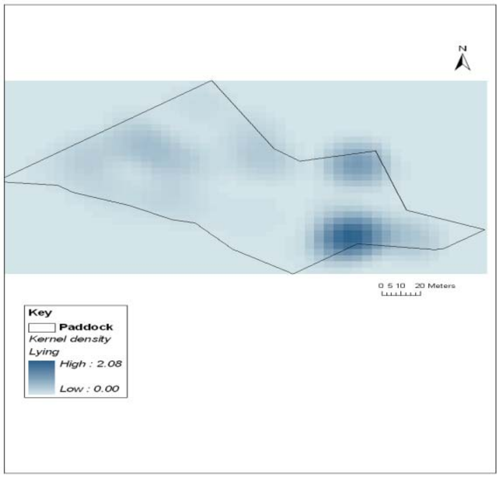
c) Paddock 7b



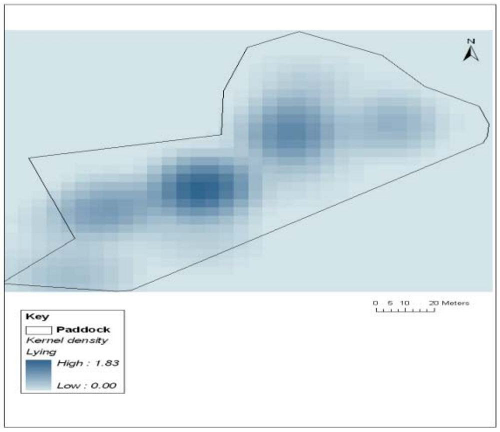
d) Paddock 17a



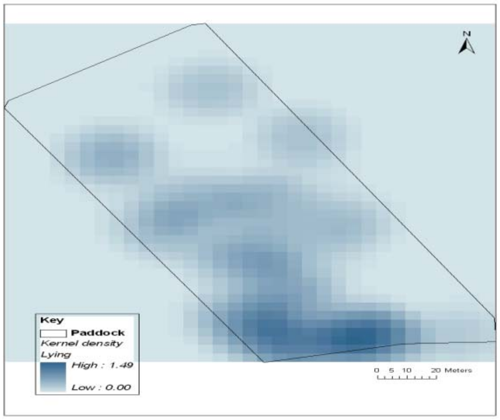
e) Paddock 17b



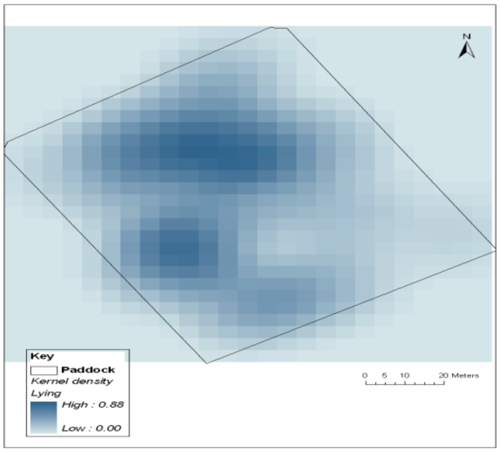
f) Paddock 29a



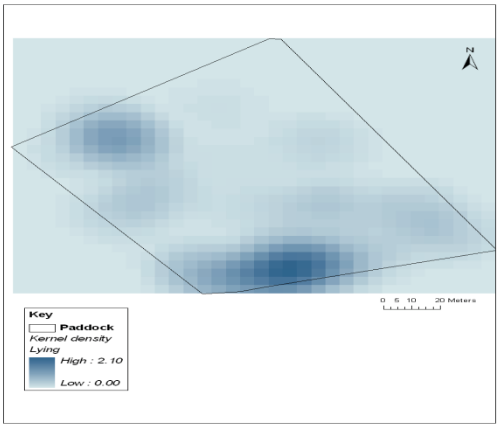
g) Paddock 29b



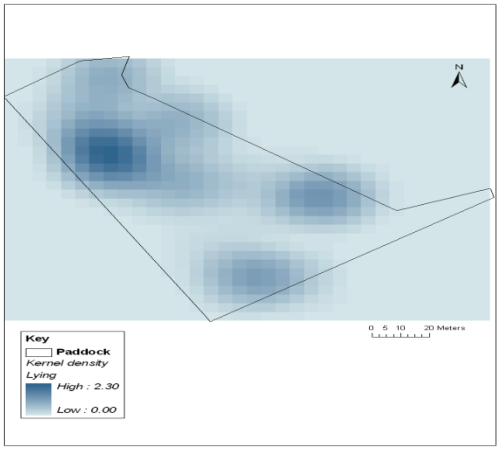
h) Paddock 60



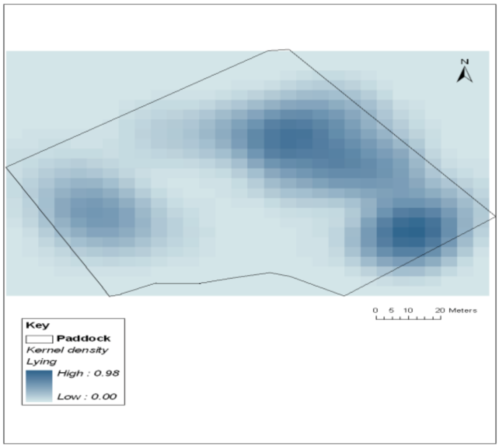
i) Paddock 61



j) Paddock 62

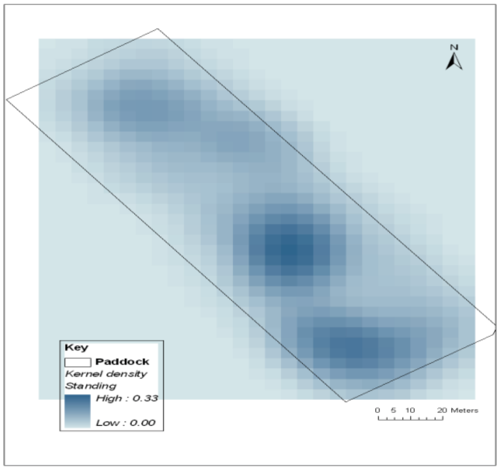


k) Paddock 78

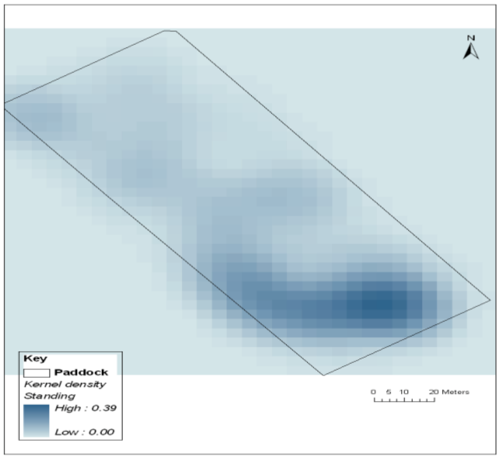


l) Paddock 79

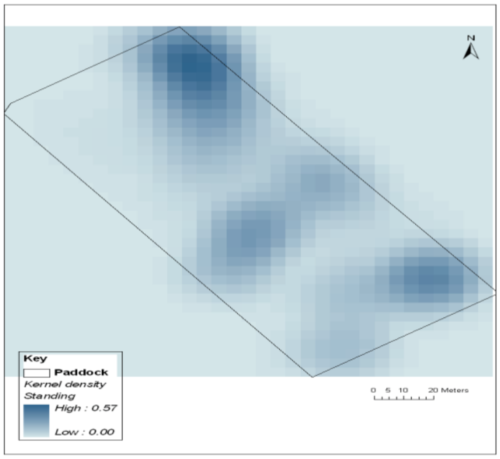
Figure A2. Kernel density estimates of lying behaviour based on a 5m x 5m cell grid for each paddock.



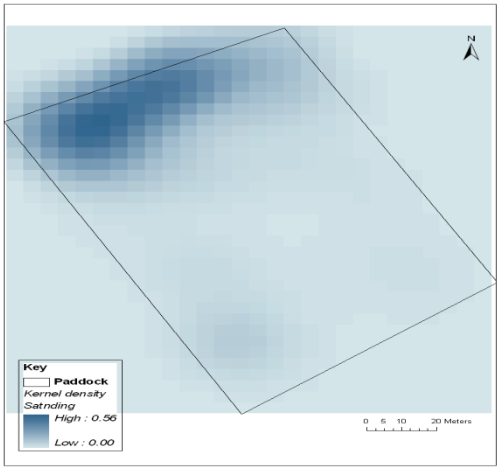
a) Paddock 6



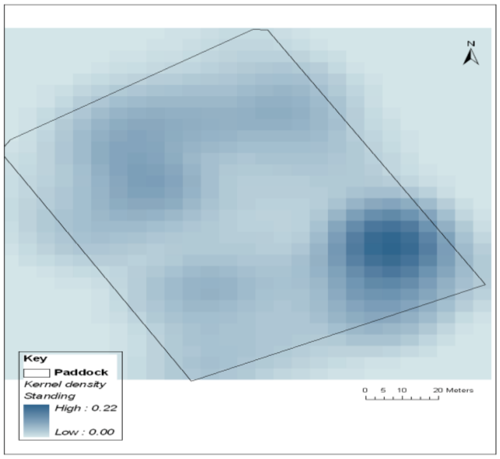
b) Paddock 7a



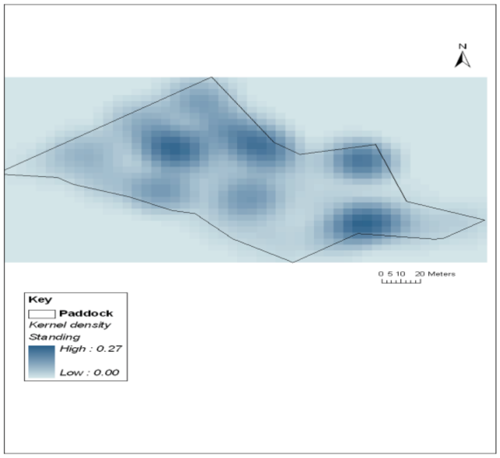
c) Paddock 7b



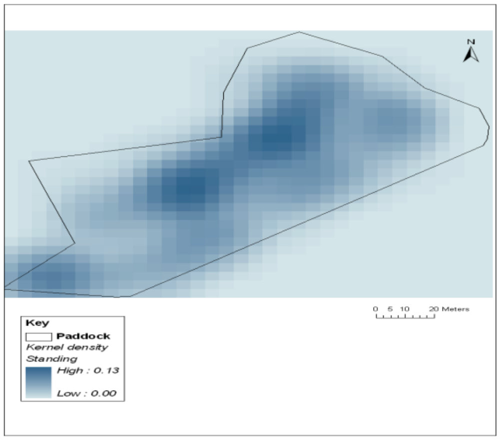
d) Paddock 17a



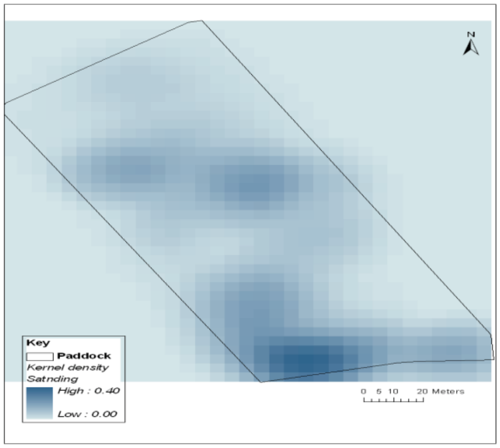
e) Paddock 17b



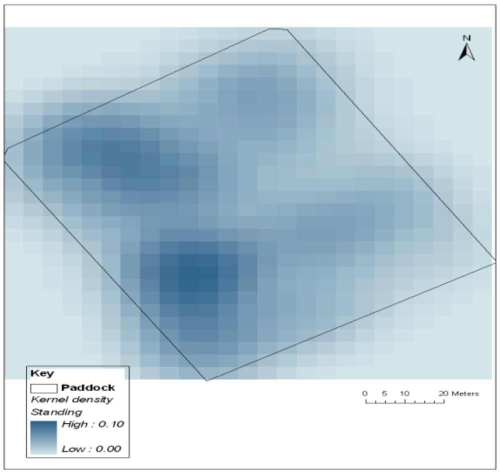
f) Paddock 29a



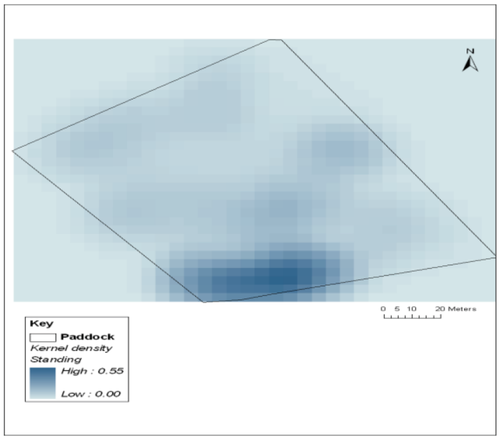
g) Paddock 29b



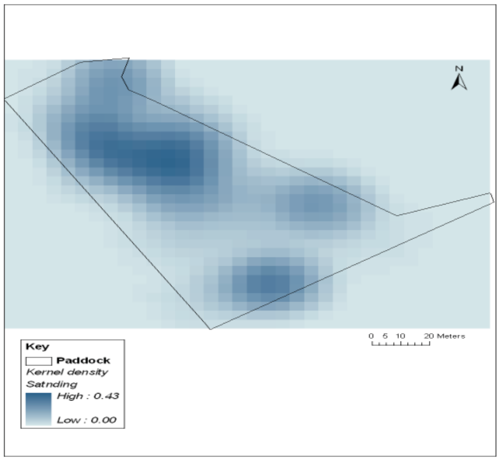
h) Paddock 60



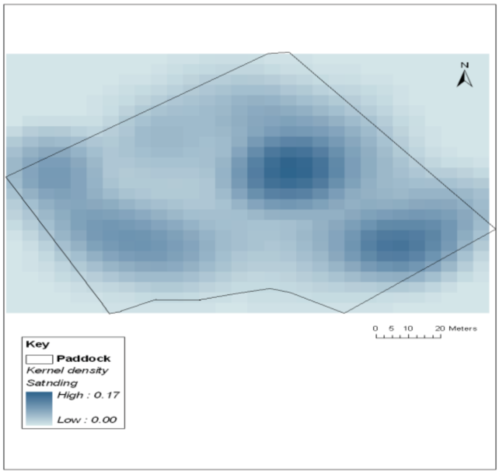
i) Paddock 61



j) Paddock 62

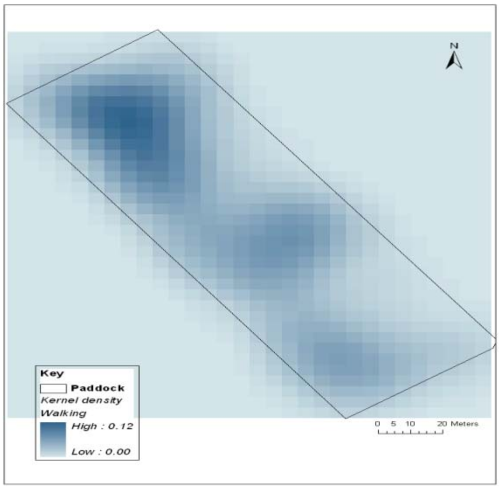


k) Paddock 78

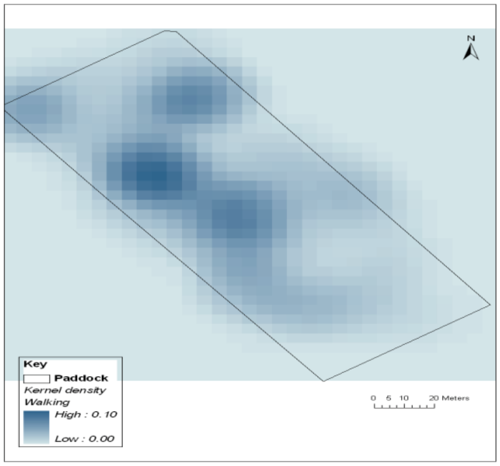


l) Paddock 79

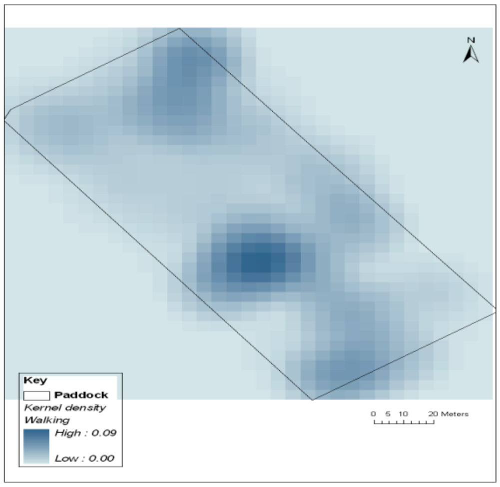
Figure A3. Kernel density estimates of standing behaviour based on a 5m x 5m cell grid for each paddock.



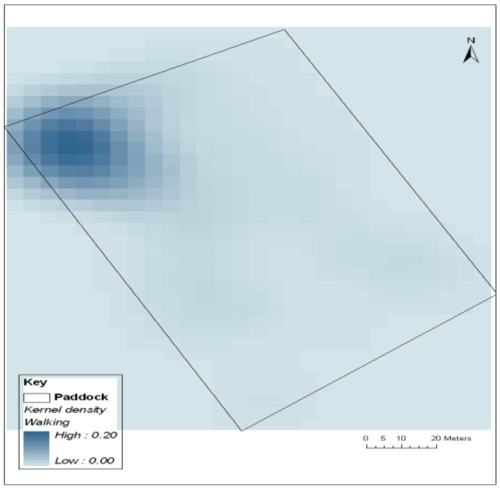
a) Paddock 6



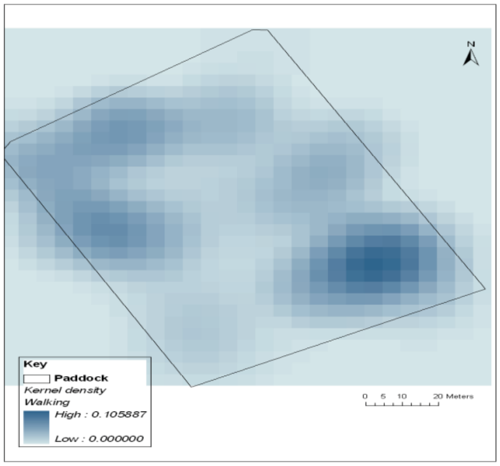
b) Paddock 7a



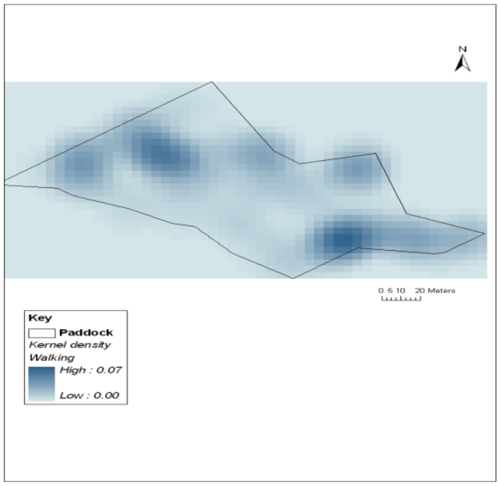
c) Paddock 7b



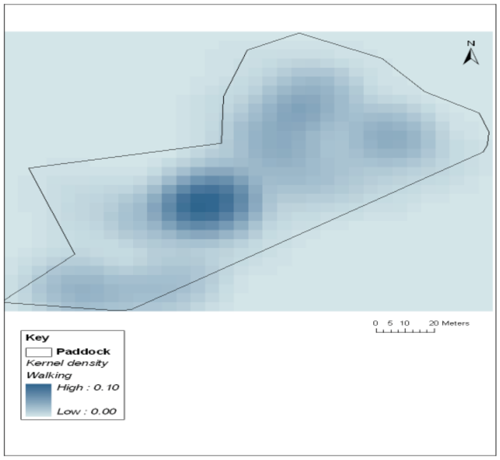
d) Paddock 17a



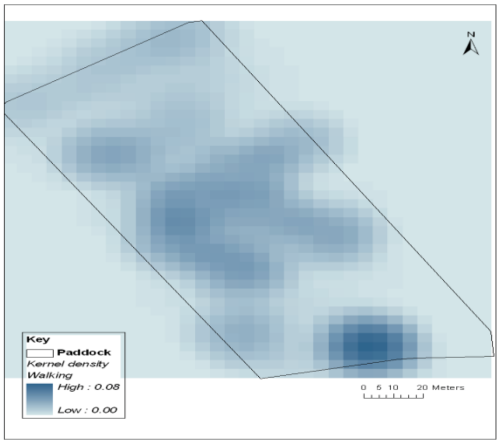
e) Paddock 17b



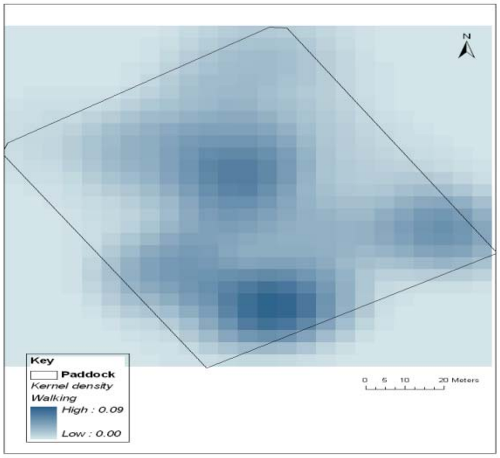
f) Paddock 29a



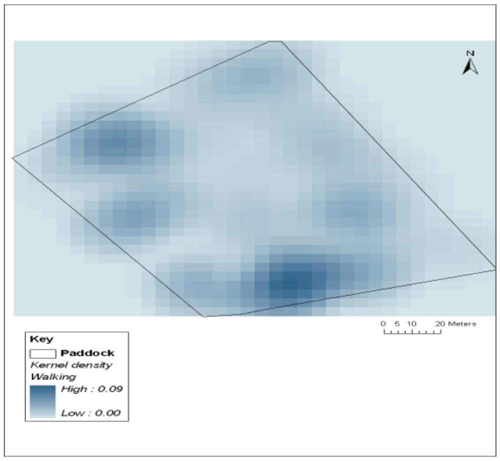
g) Paddock 29b



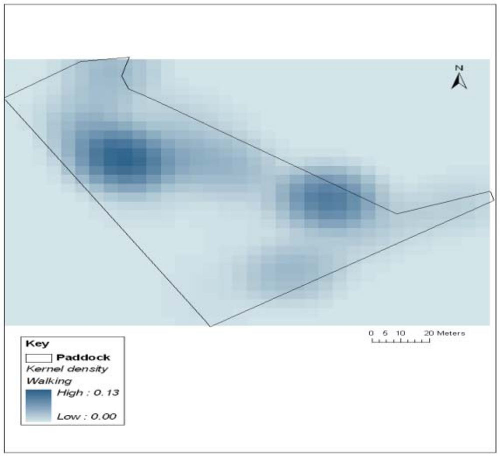
h) Paddock 60



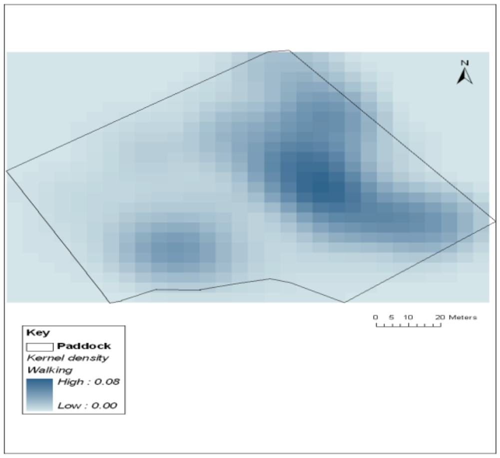
i) Paddock 61



j) Paddock 62

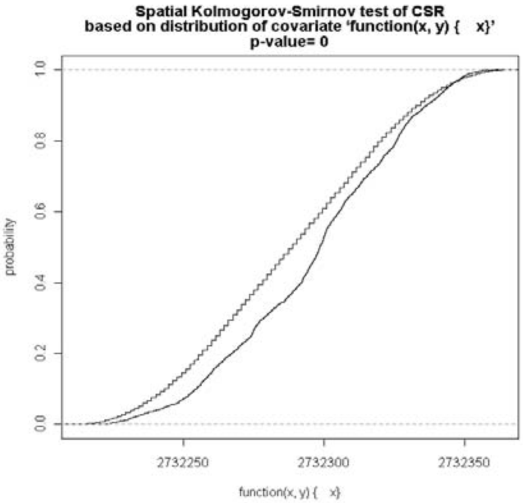


k) Paddock 78

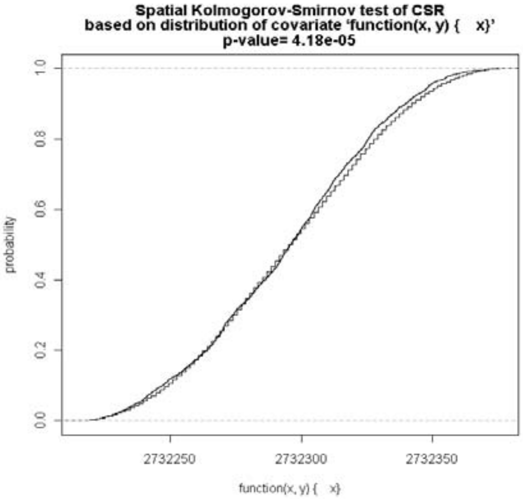


l) Paddock 79

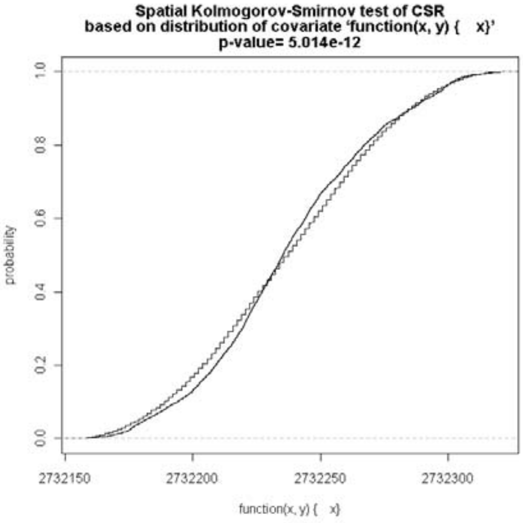
Figure A4. Kernel density estimates of walking behaviour based on a 5m x 5m cell grid for each paddock.



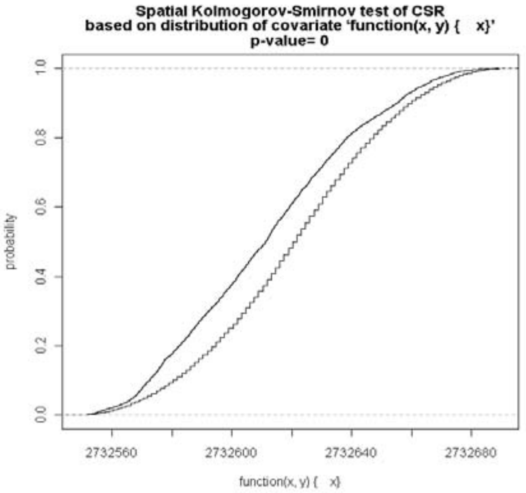
a) Paddock 6



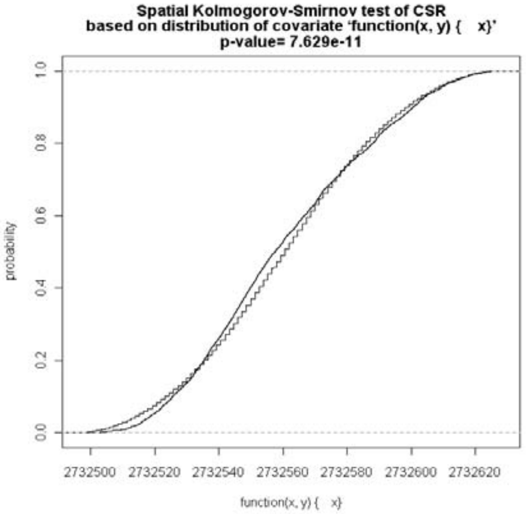
b) Paddock 7a



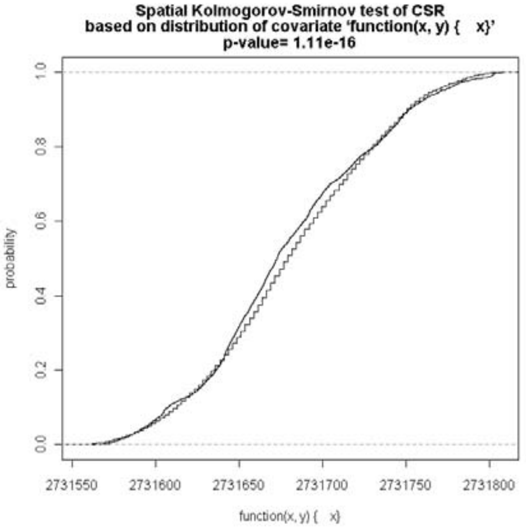
c) Paddock 7b



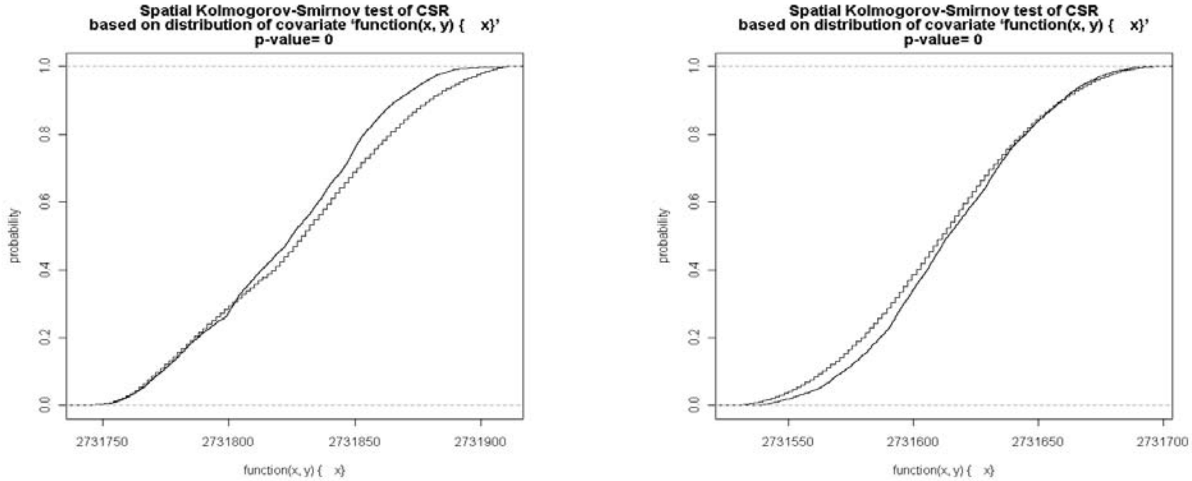
d) Paddock 17a



e) Paddock 17b

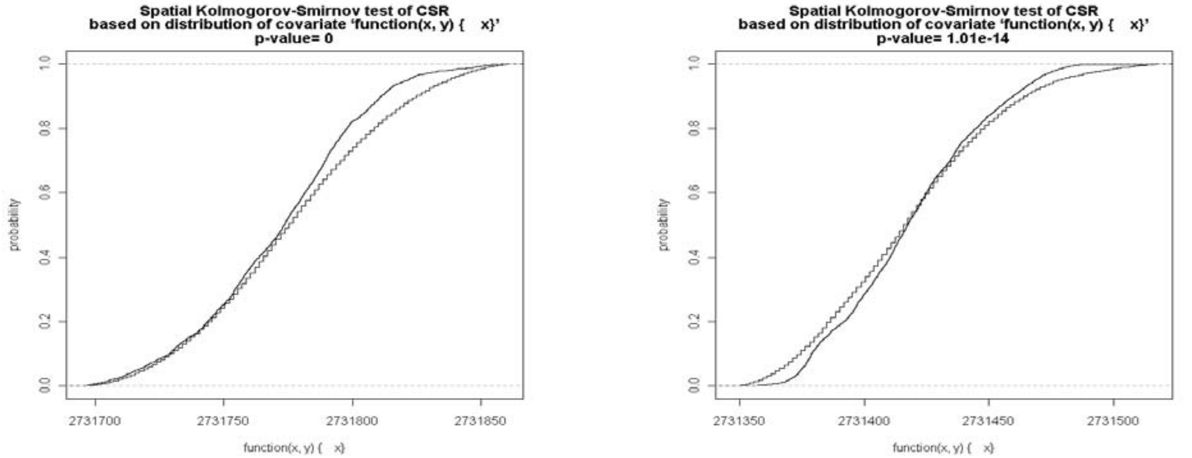


f) Paddock 29a



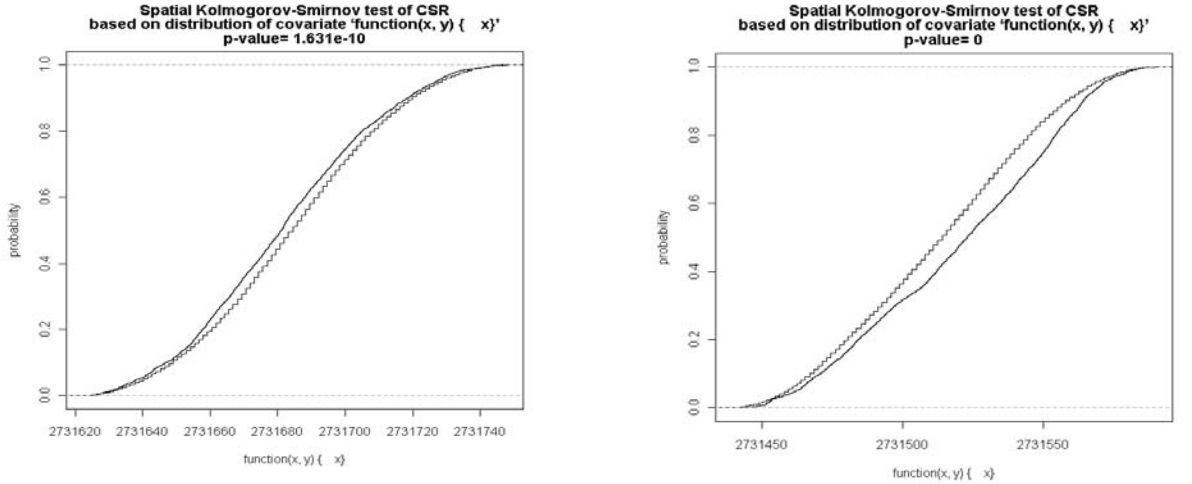
g) Paddock 29b

j) Paddock 62



h) Paddock 60

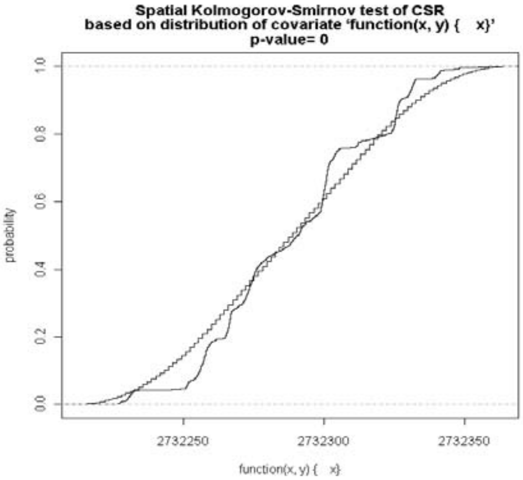
k) Paddock 78



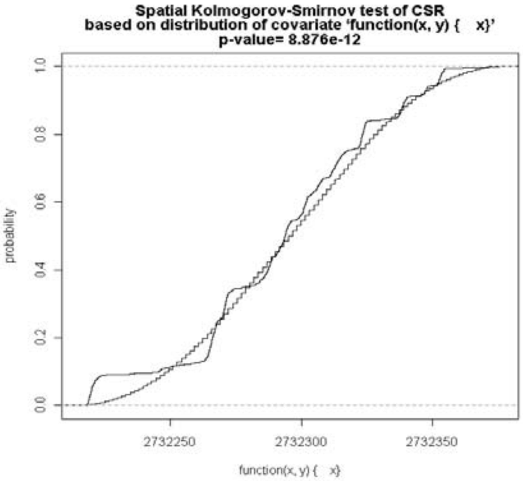
i) Paddock 61

l) Paddock 79

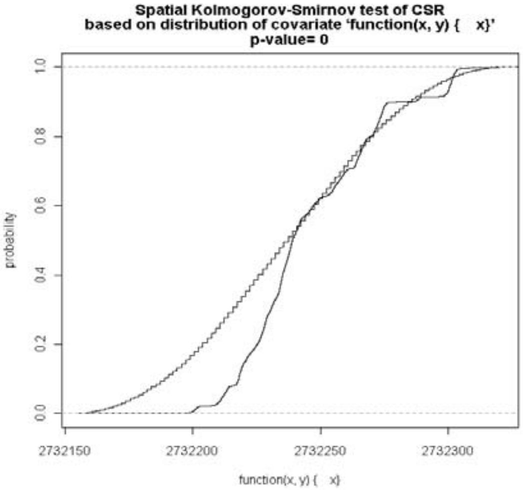
Figure A5. Results from Kolmogorov-Smirnov test for Complete Spatial Randomness of grazing behaviour for each paddock. Deviations of the observed data distribution from the normal curve (predicted distribution) indicate aggregation of grazing within particular areas of the paddock.



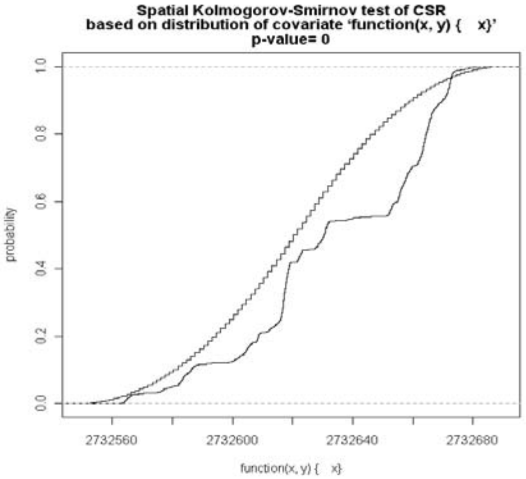
a) Paddock 6



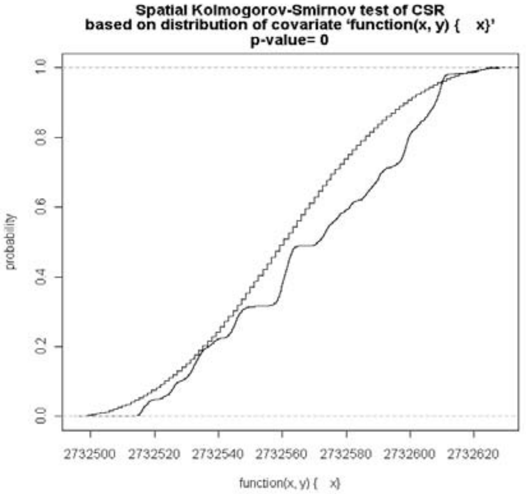
b) Paddock 7a



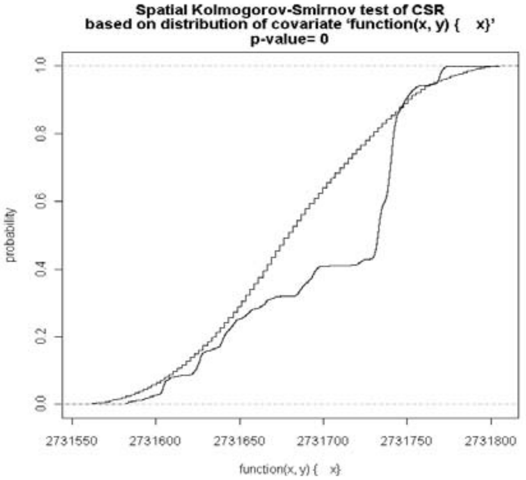
c) Paddock 7b



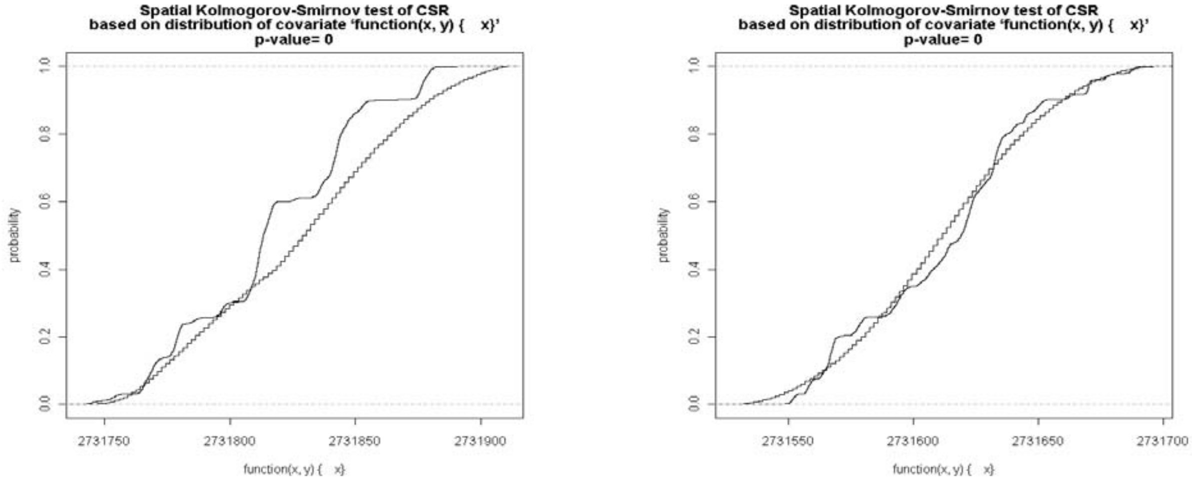
d) Paddock 17a



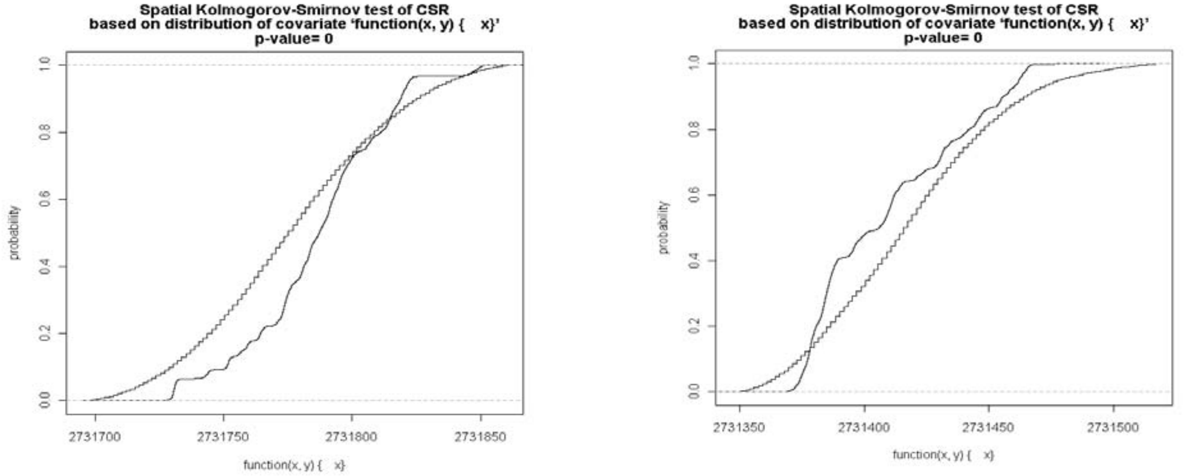
e) Paddock 17b



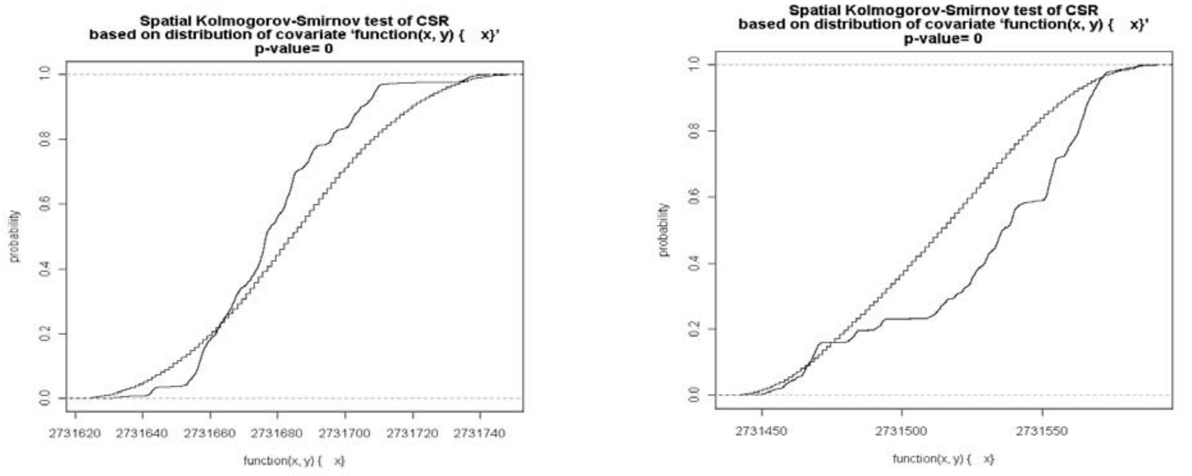
f) Paddock 29a



g) Paddock 29b
j) Paddock 62

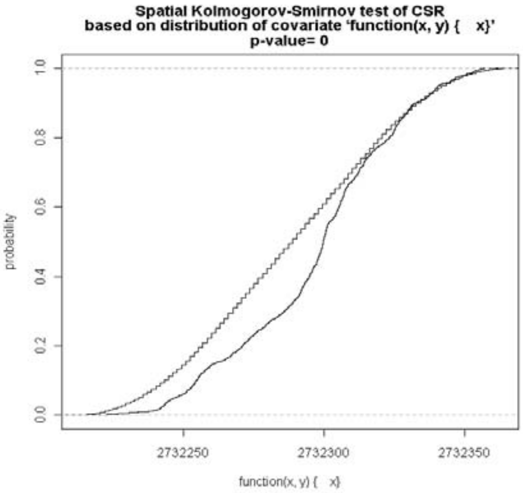


h) Paddock 60
k) Paddock 78

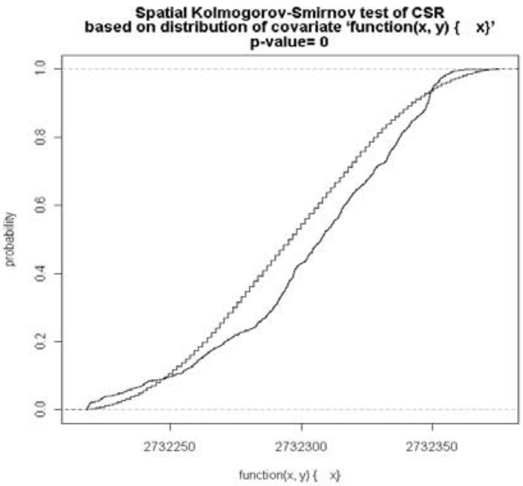


i) Paddock 61
l) Paddock 79

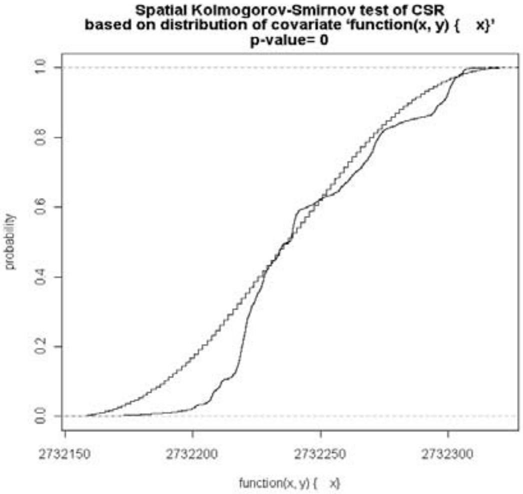
Figure A6. Results from Kolmogorov-Smirnov test for Complete Spatial Randomness of lying behaviour for each paddock. Deviations of the observed data distribution from the normal curve (predicted distribution) indicate aggregation of lying within particular areas of the paddock.



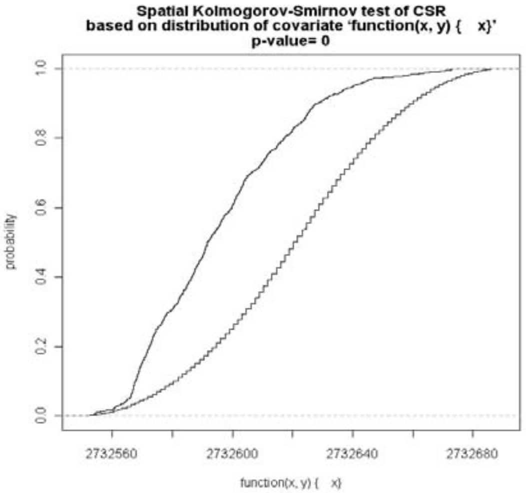
a) Paddock 6



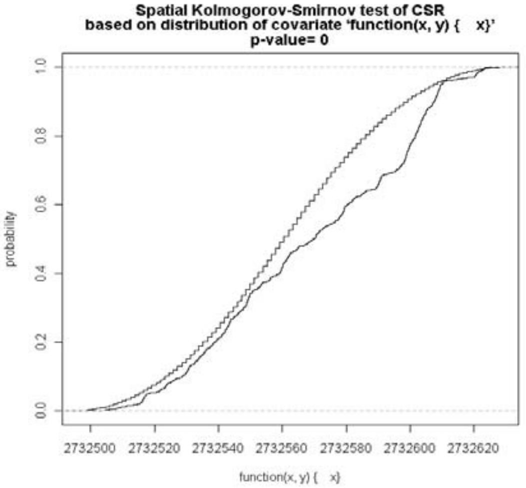
b) Paddock 7a



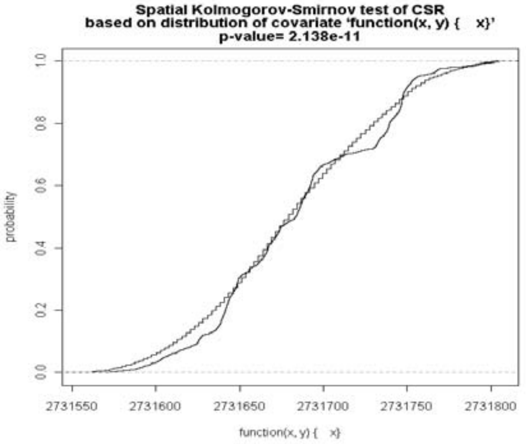
c) Paddock 7b



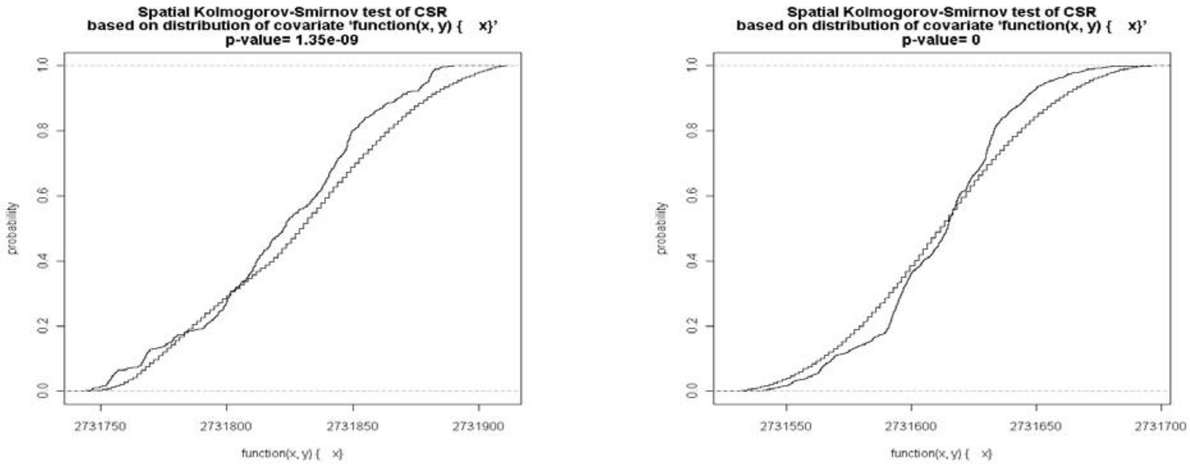
d) Paddock 17a



e) Paddock 17b

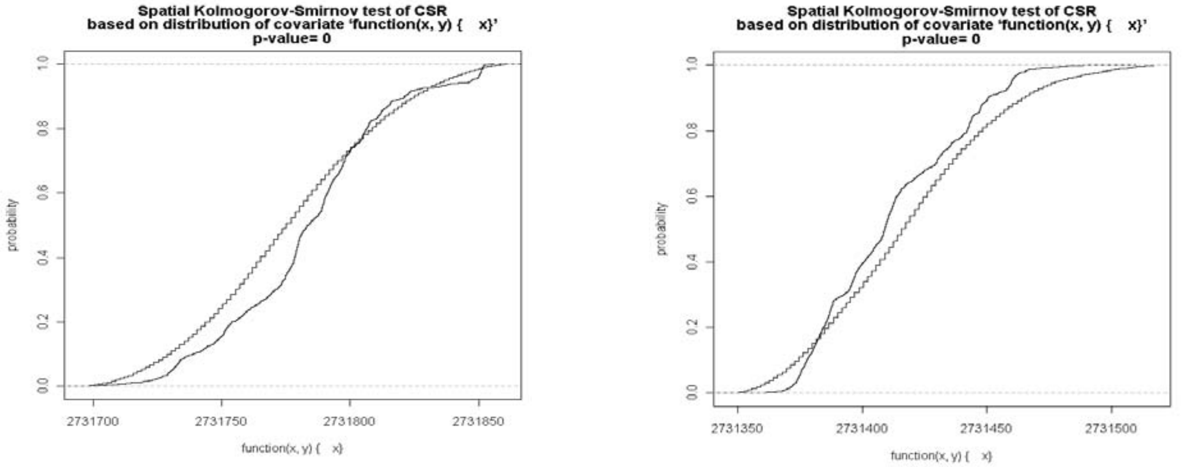


f) Paddock 29a



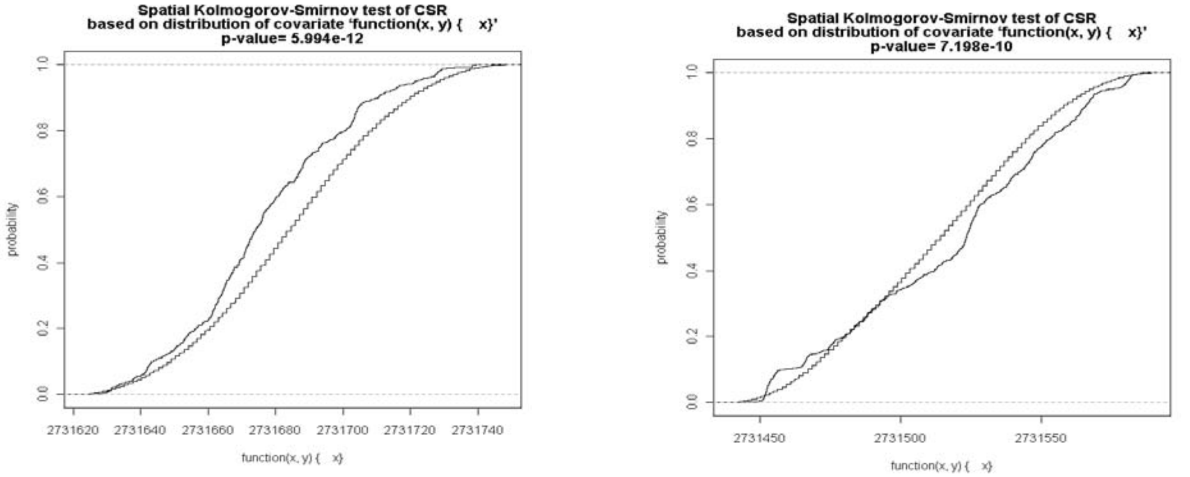
g) Paddock 29b

j) Paddock 62



h) Paddock 60

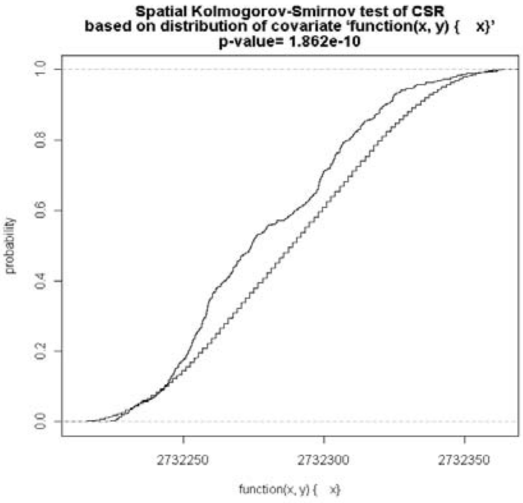
k) Paddock 78



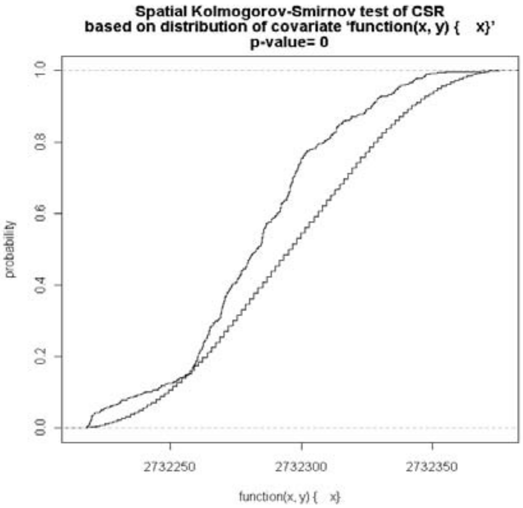
i) Paddock 61

l) Paddock 79

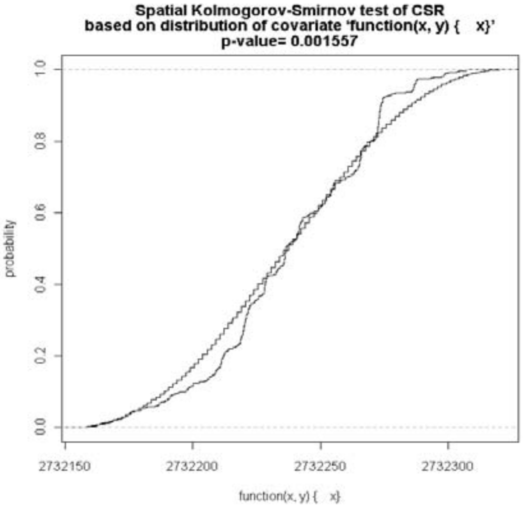
Figure A7. Results from Kolmogorov-Smirnov test for Complete Spatial Randomness of standing behaviour for each paddock. Deviations of the observed data distribution from the normal curve (predicted distribution) indicate aggregation of standing within particular areas of the paddock.


Spatial Kolmogorov-Smirnov test of CSR
based on distribution of covariate 'function(x, y) { x}'
p-value= 1.862e-10

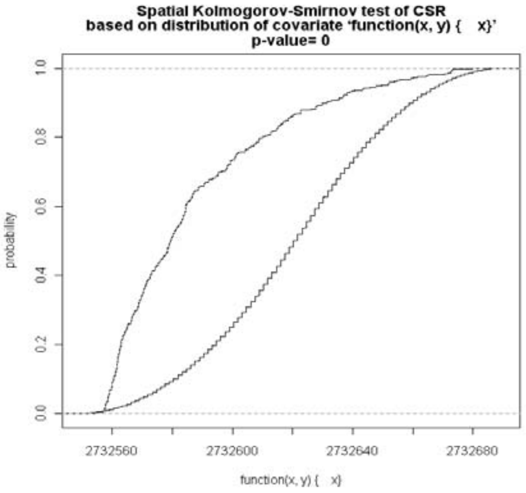
a) Paddock 6


Spatial Kolmogorov-Smirnov test of CSR
based on distribution of covariate 'function(x, y) { x}'
p-value= 0

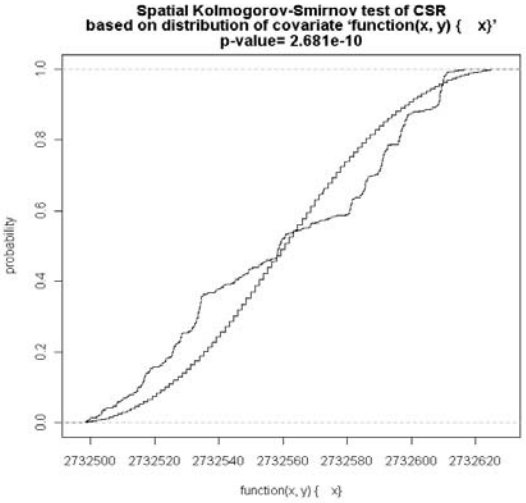
b) Paddock 7a


Spatial Kolmogorov-Smirnov test of CSR
based on distribution of covariate 'function(x, y) { x}'
p-value= 0.001557

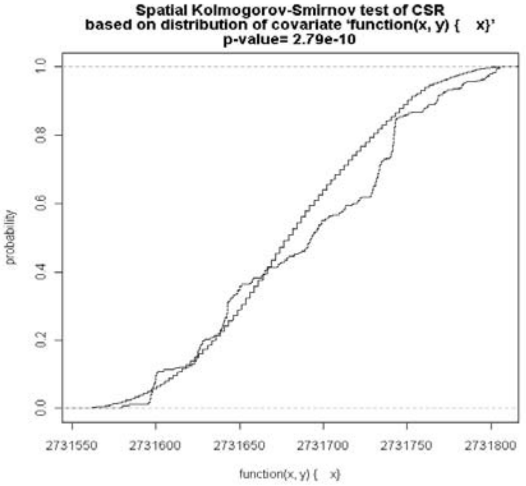
c) Paddock 7b


Spatial Kolmogorov-Smirnov test of CSR
based on distribution of covariate 'function(x, y) { x}'
p-value= 0

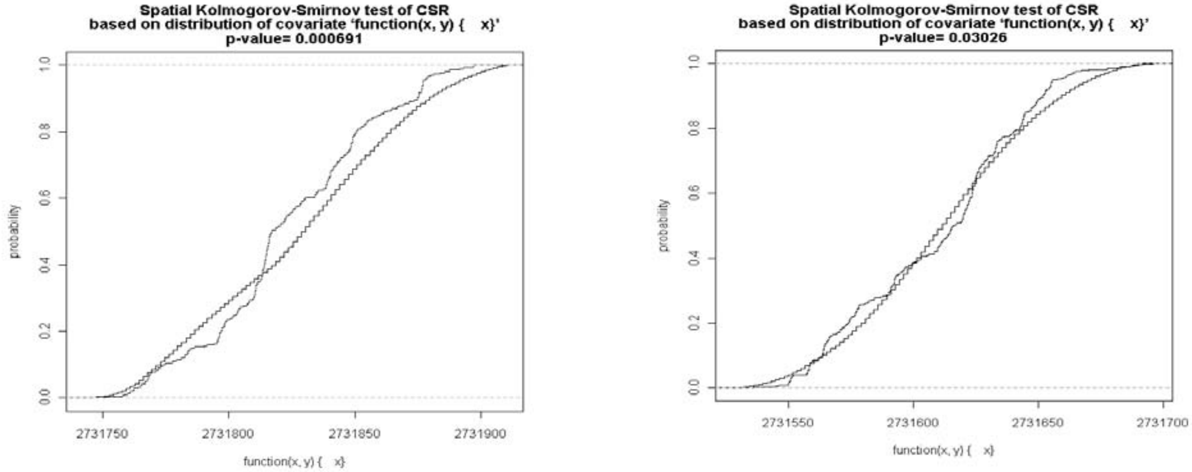
d) Paddock 17a


Spatial Kolmogorov-Smirnov test of CSR
based on distribution of covariate 'function(x, y) { x}'
p-value= 2.681e-10

e) Paddock 17b

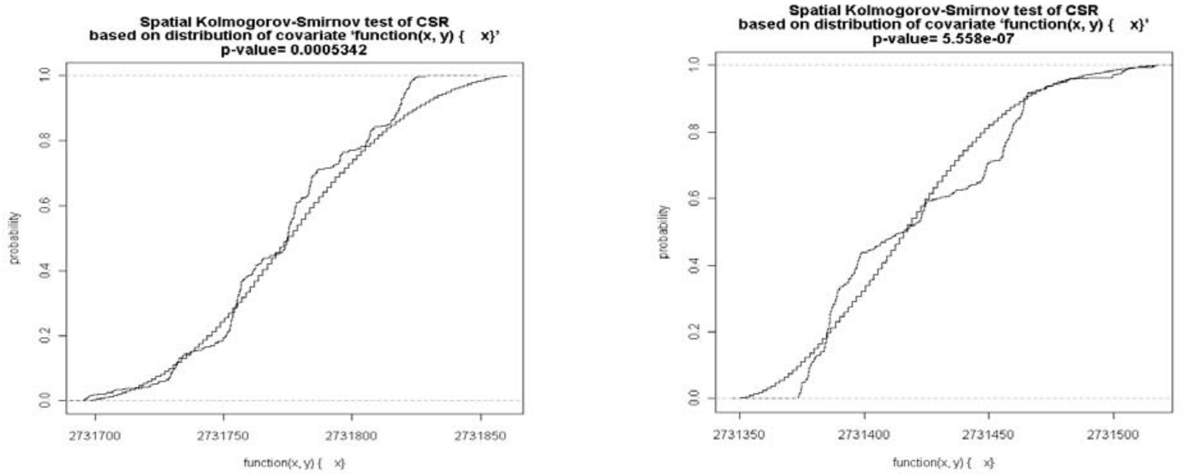

Spatial Kolmogorov-Smirnov test of CSR
based on distribution of covariate 'function(x, y) { x}'
p-value= 2.79e-10

f) Paddock 29a



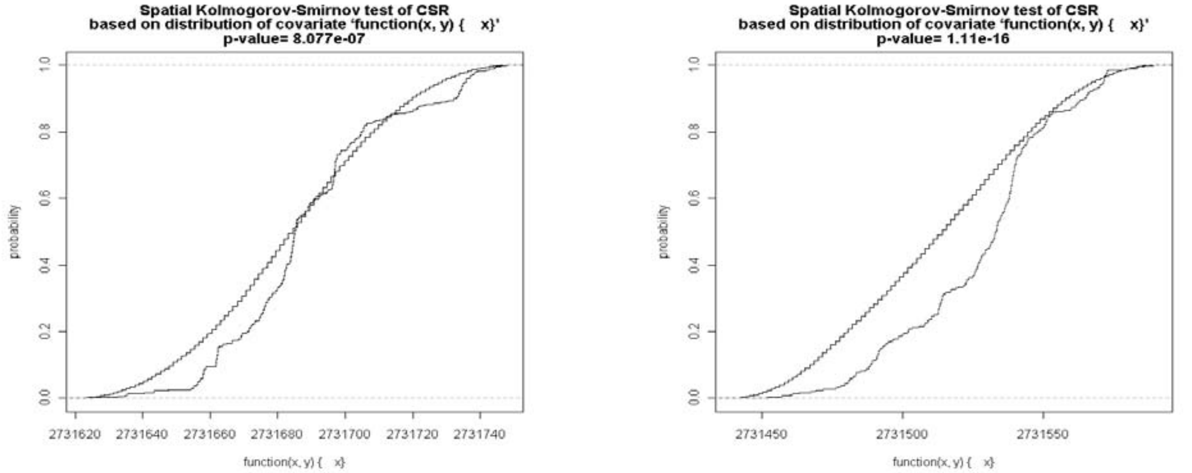
g) Paddock 29b

j) Paddock 62



h) Paddock 60

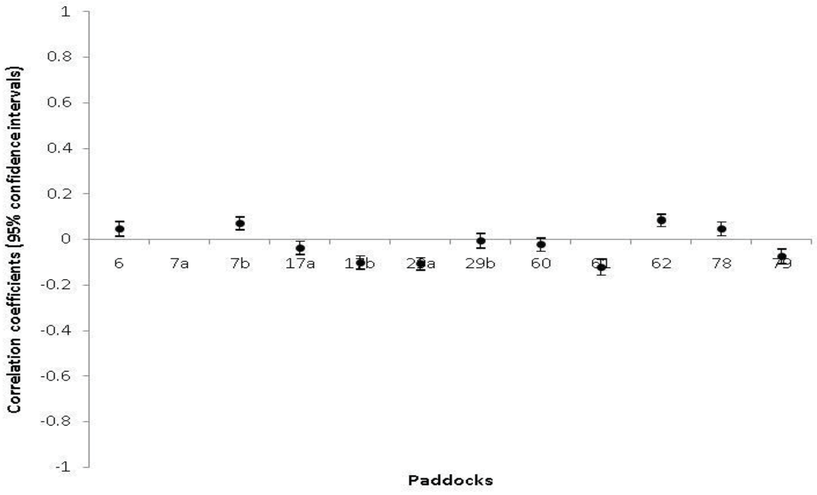
k) Paddock 78



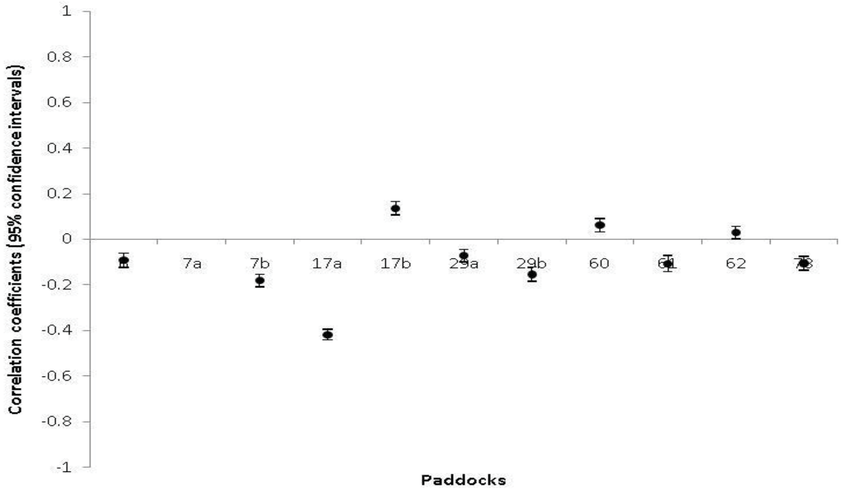
i) Paddock 61

l) Paddock 79

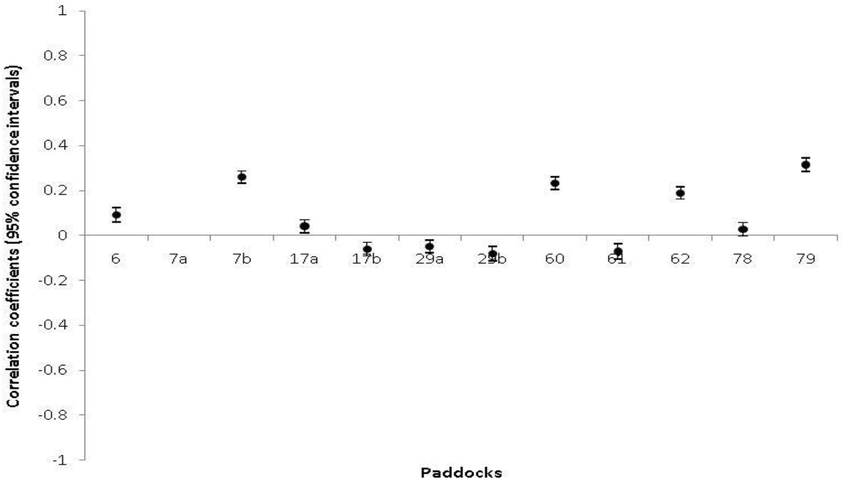
Figure A8. Results from Kolmogorov-Smirnov test for Complete Spatial Randomness of walking behaviour for each paddock. Deviations of the observed data distribution from the normal curve (predicted distribution) indicate aggregation of walking within particular areas of the paddock.



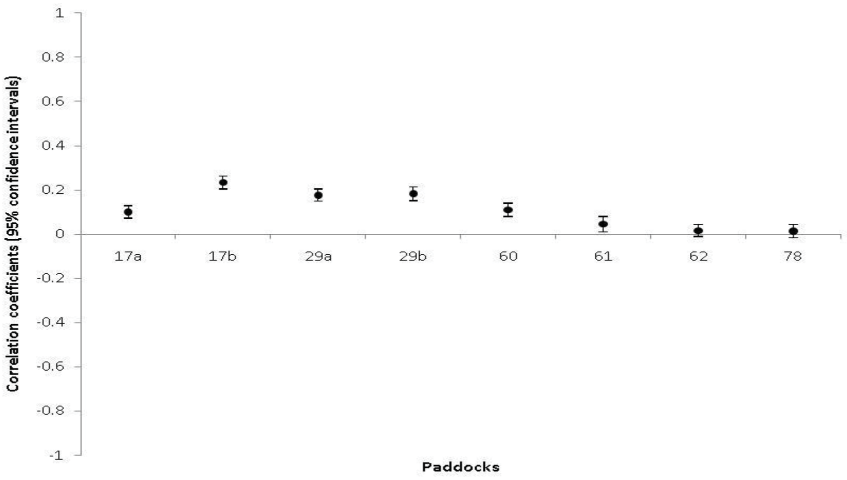
a) *Aspect*



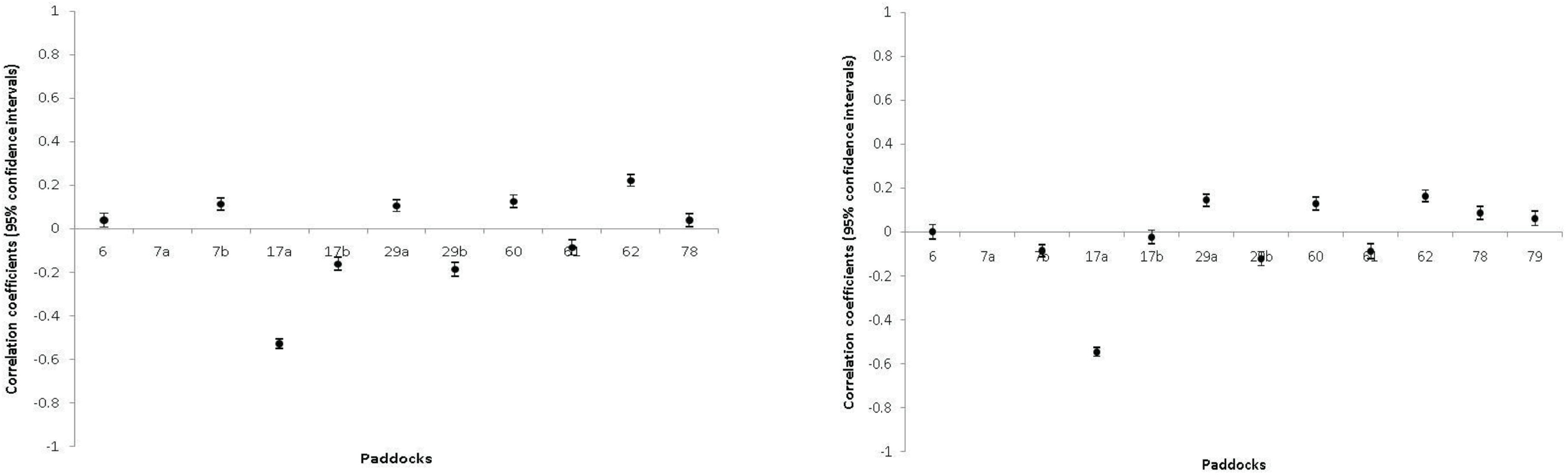
c) *Slope*



b) *Elevation*



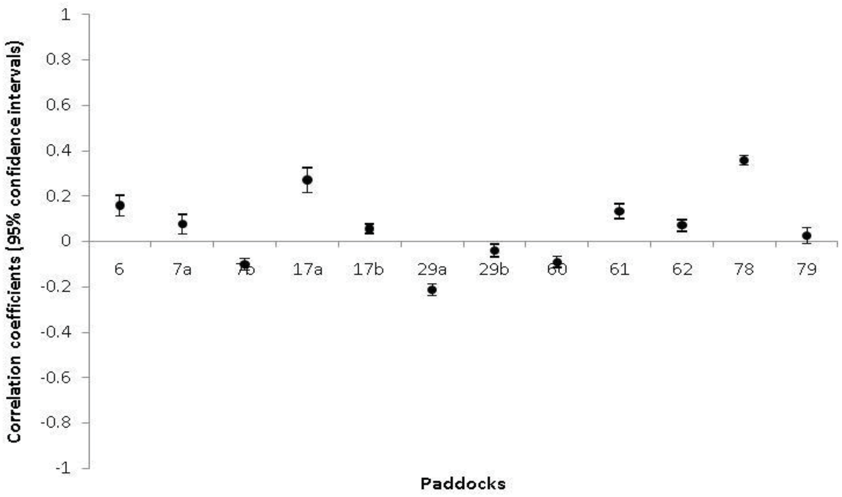
d) P_{mass}



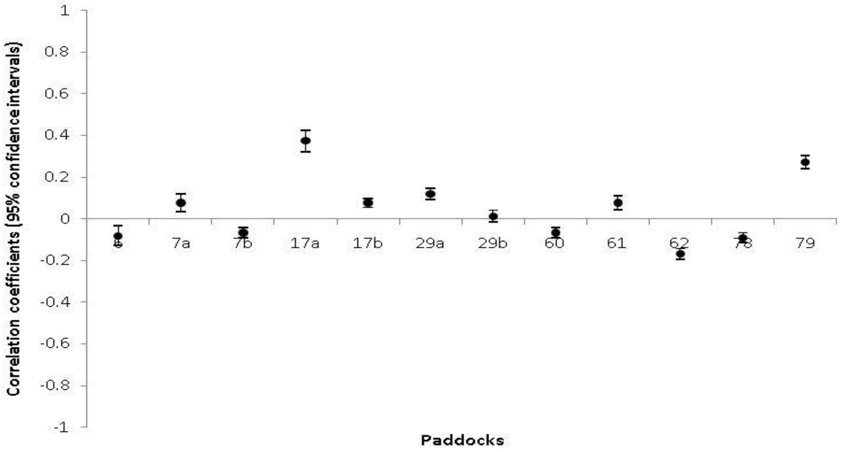
e) W_{dis}

f) G_{dis}

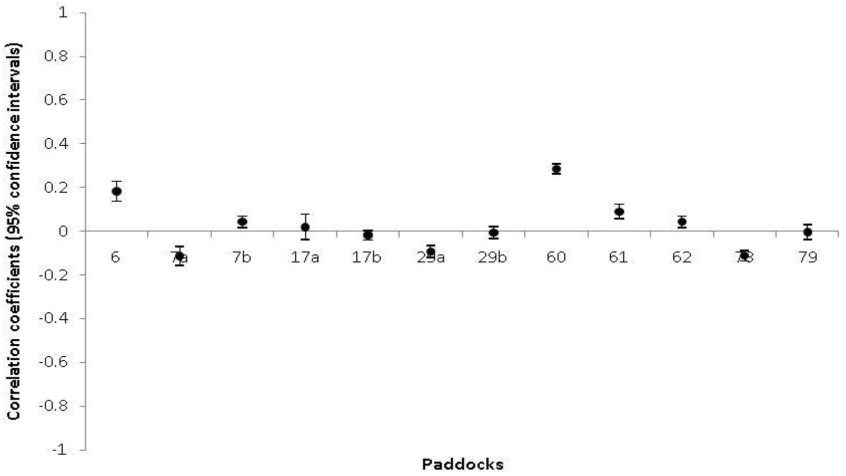
Figure A9. Correlation coefficients of grazing behaviour and environmental factors for each paddock.



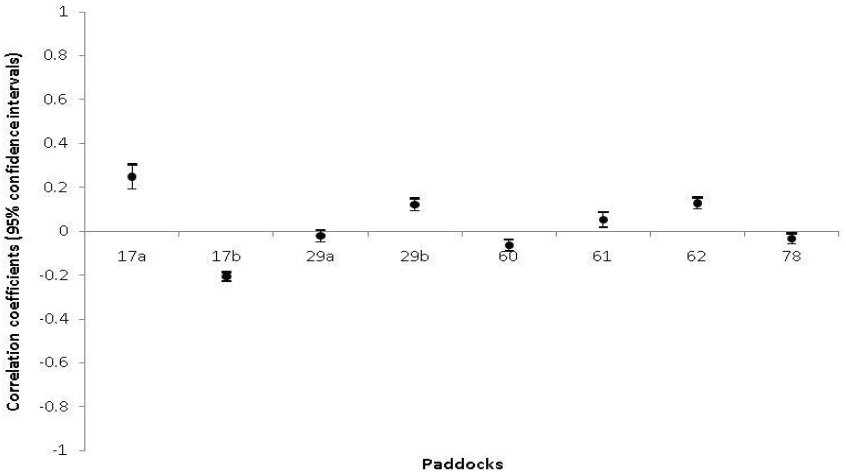
a) Aspect



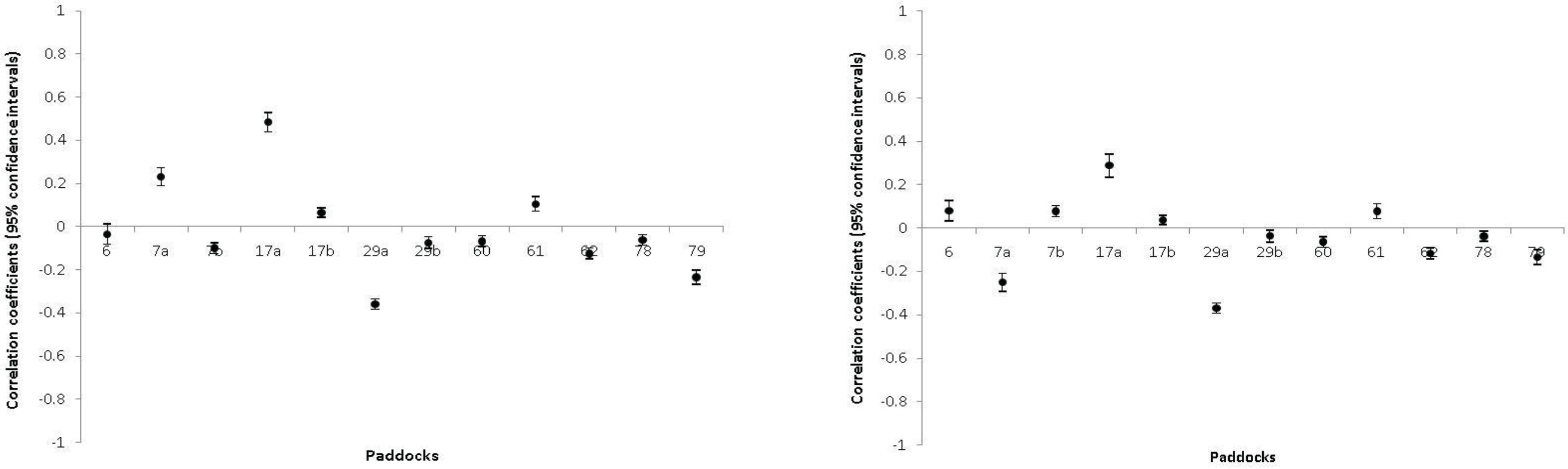
b) Elevation



c) Slope



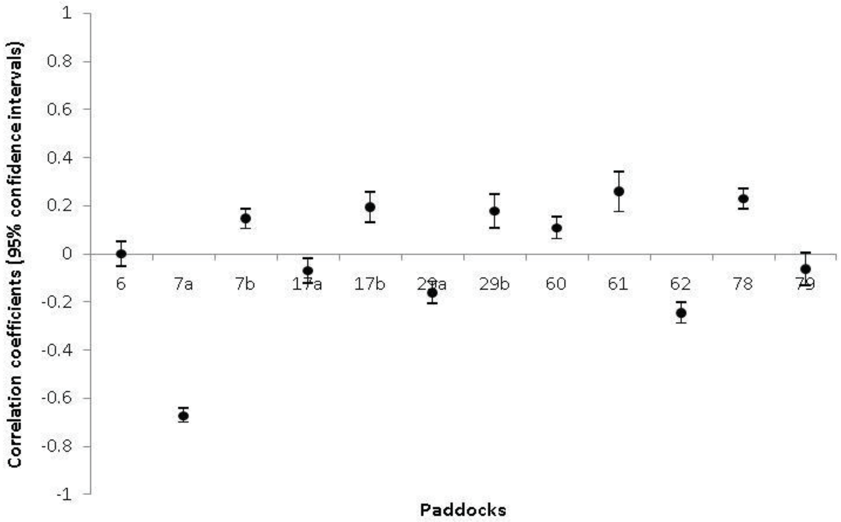
d) P_{mass}



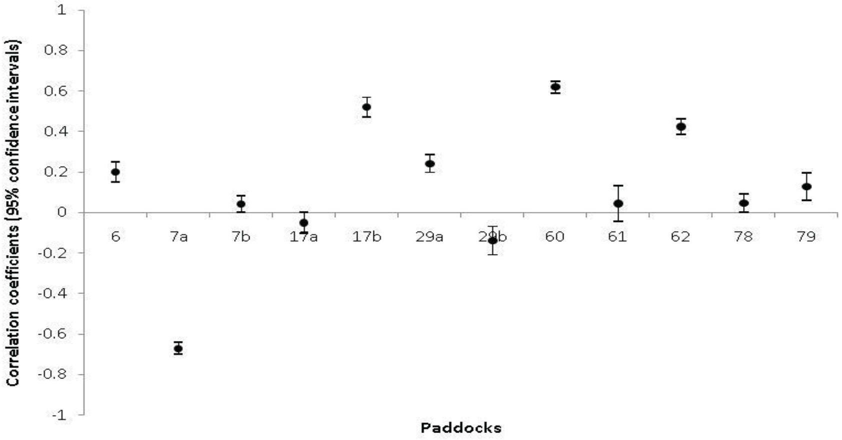
e) W_{dis}

f) G_{dis}

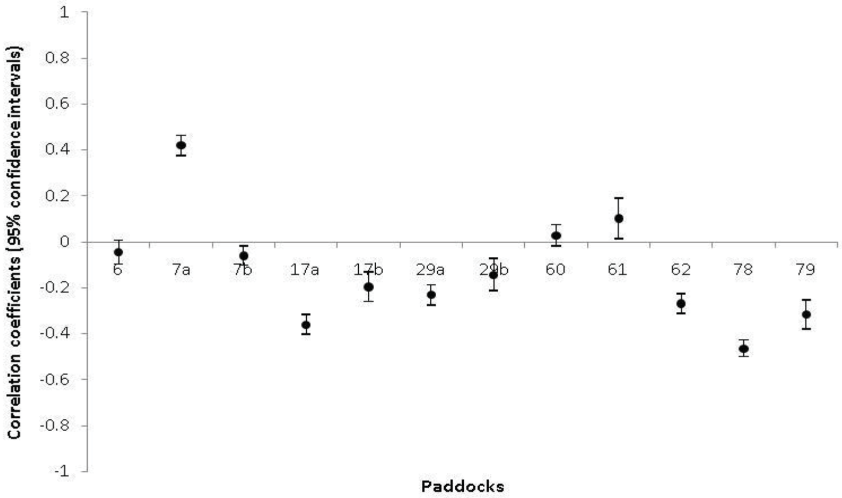
Figure A10. Correlation coefficients of lying behaviour and environmental factors for each paddock.



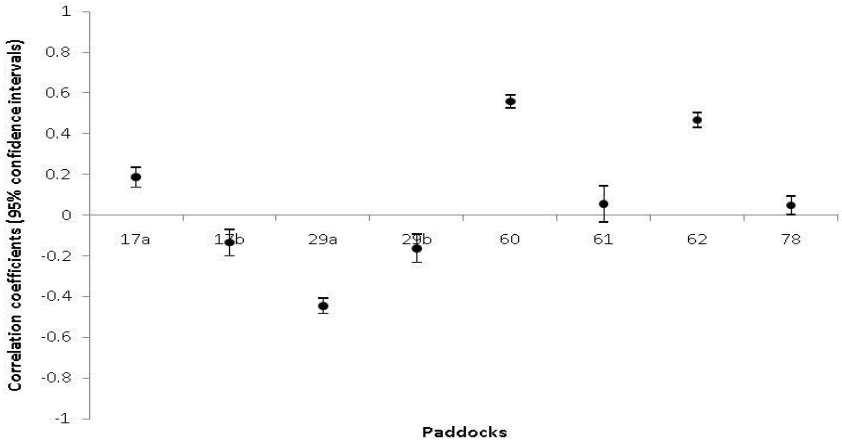
a) Aspect



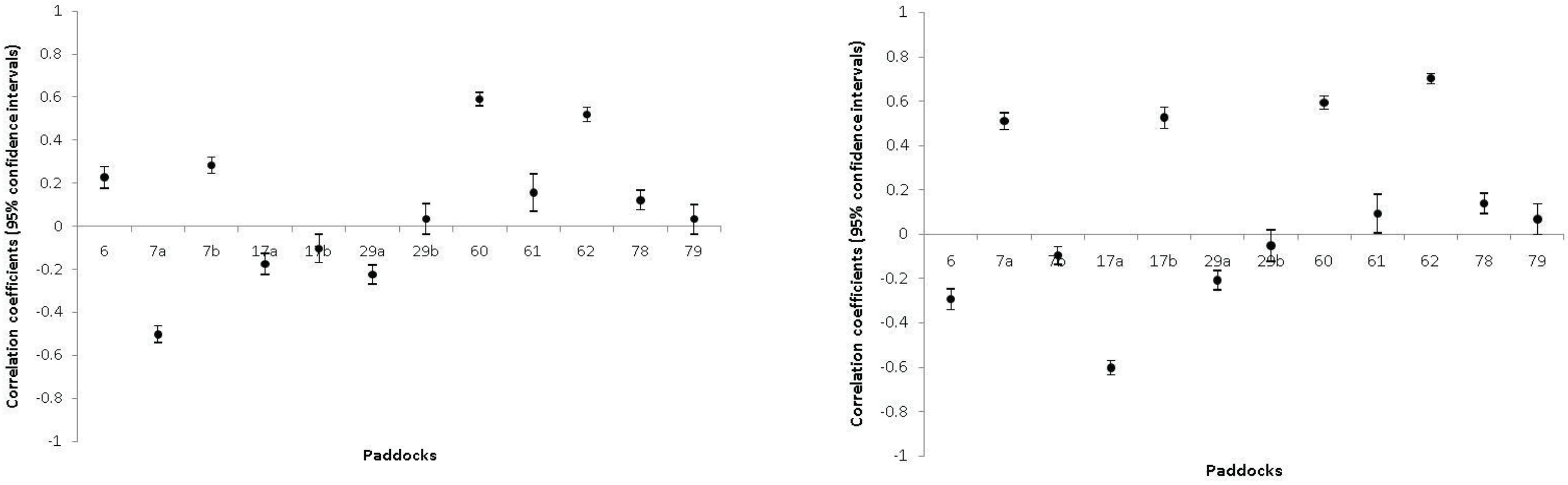
b) Elevation



c) Slope



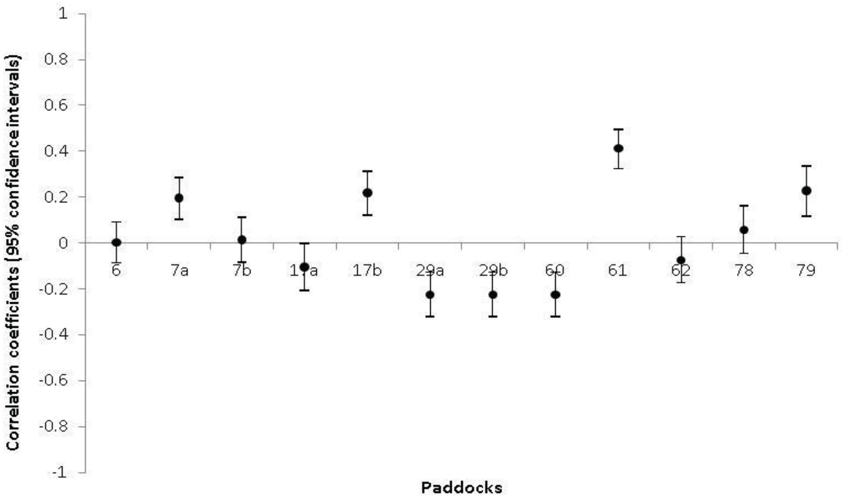
d) P_{mass}



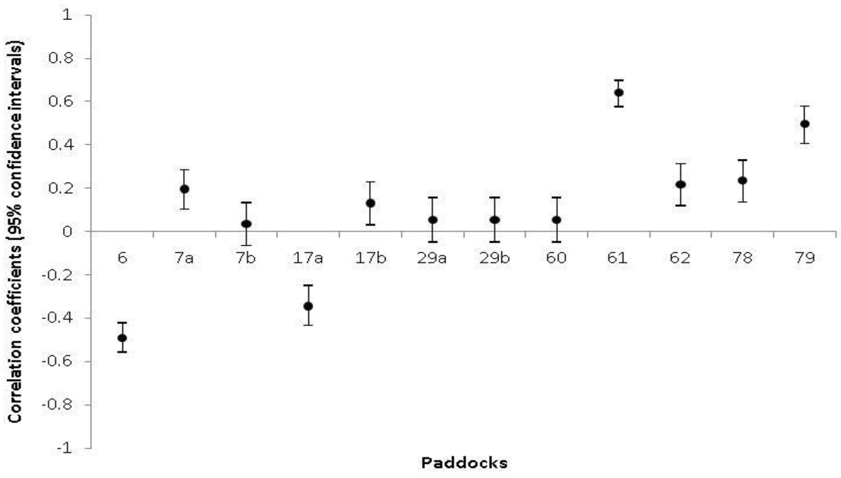
e) W_{dis}

f) G_{dis}

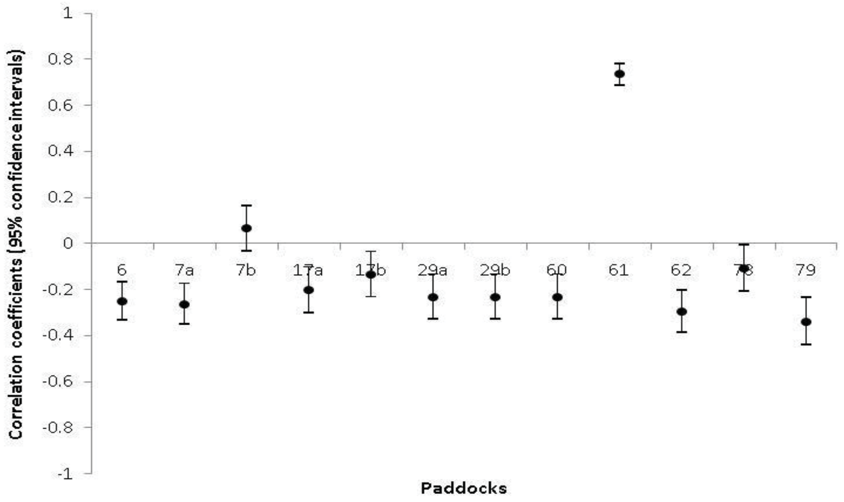
Figure A11. Correlation coefficients of standing behaviour and environmental factors for each paddock.



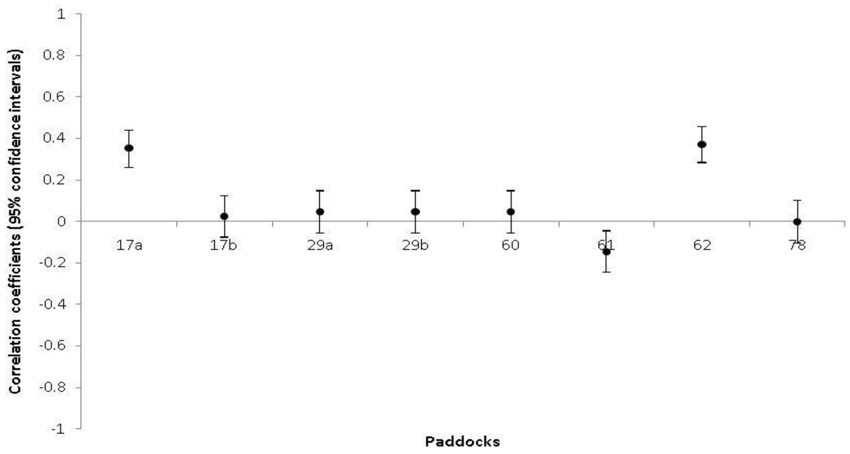
a) *Aspect*



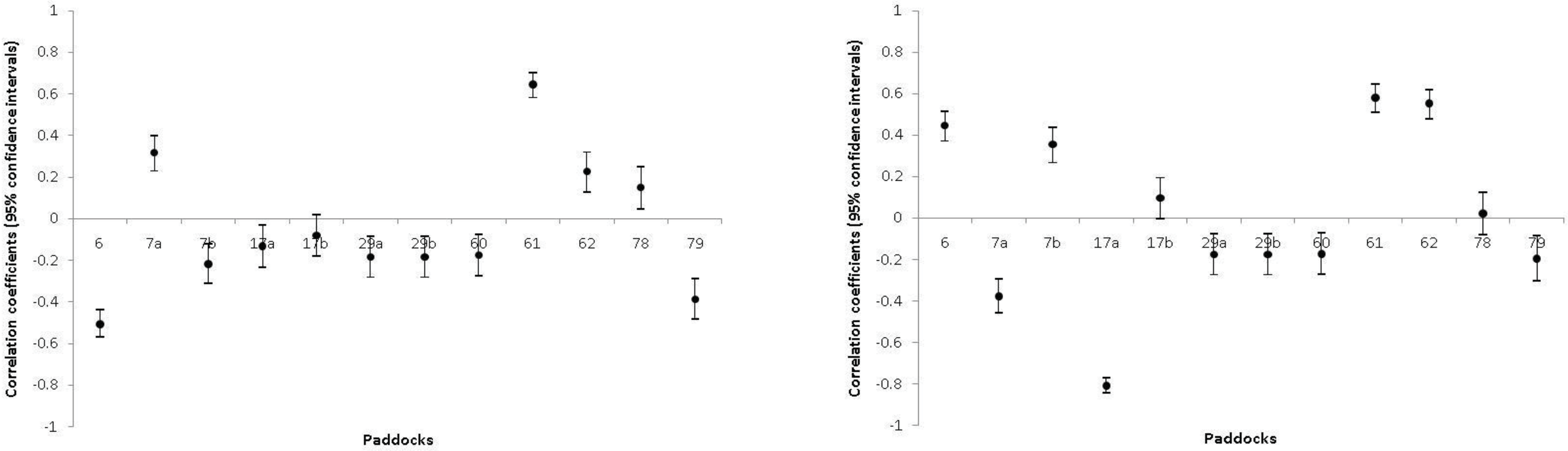
b) *Elevation*



c) *Slope*



d) P_{mass}



e) W_{dis} *f)* G_{dis}

Figure A12. Correlation coefficients of walking behaviour and environmental factors for each paddock.