Ranking paddock performance using data automatically collected in a New Zealand dairy farm milking system

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

Masters

in

Agriculture

At Massey University, Manawatu, New Zealand.

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2014

Abstract

Knowledge of individual paddock performance can assist management decisions and contribute to improved productivity and profitability of dairy farms. Annual paddock performance is typically assessed by estimating the net herbage accumulation through regular ‘farm walks,’ but this is not a routine practice on many dairy farms. The aim of this research was to test the hypothesis that automated daily records of milk production could be used in conjunction with the number of cow grazing events to rank paddocks according to their annual net herbage accumulation. This required the assignment of herd milk yield values at AM and PM milkings to the corresponding paddock grazed, along with records of the number of cows present.

Automated recording of grazing events was required and achieved using GPS devices on a small number of cows per herd. The minimum requirement of GPS devices was tested by a simulation process to determine suitability for this task. The simulation process identified that three GPS units were required per herd of cows, with each fixing one position per paddock entered. The units needed have a 95% circular error probable of 6m (+/- 6m) or better.

Prior to field trials, the DairyNZ Whole Farm Model was used to collect two seasons of data. Milk yield data, number of cows in the herd and paddock grazed were used to test the hypothesis. The number of grazing events for each paddock was a good predictor of the ranking of net herbage accumulation per paddock, with an r value of 0.92. Prediction using milk yield was also reliable (r = 0.82).

Following the modelling results, a year-long field trial was conducted on a commercial dairy farm between December 2011 and 2012 to further test the hypothesis. All measures of performance had similar spreads of data (>100%); however no measures ranked paddocks in a similar order to that of herbage accumulation. Consequently no association was evident between the ranking order of paddocks by grazing events and herbage accumulation, likewise no association between milk production and herbage accumulation. There was a significant association between calculated pasture eaten and herbage accumulation however this method failed to identify the poorest performing paddocks.

Two probable reasons that no method accurately ranked paddock performance in terms of herbage accumulation were; the accuracy of estimated herbage accumulation figures and the accuracy of the estimated figures of supplements fed in the paddock and the level of wastage occurring. The extent that pasture management practices and preferences have on dictating the measured performance is also unknown and may have also been a leading factor in the poor correlation. Furthermore, ambiguity surrounds the relationship between daily intake and daily milk production and how long it takes for feed eaten to be harvested as milk. A clearer understanding of why the performance measures do not match is required before they can be used as a proxy for herbage accumulation.

Acknowledgements

Firstly I would like to thank DairyNZ for providing me with the opportunity and resources to undertake this study. A big thank you to my supervisors, Dr Jenny Jago from DairyNZ and Prof. Ian Yule from Massey University for their support and advice offered.

Thanks to my support team at DairyNZ (Alvaro Romera, Barbara Dow, Barbara Kuhn-Sherlock Dave Clark, and Chris Glassey) for the guidance and insights on interpreting the results as I moved through this project. Thanks to all the dozen plus research technicians that helped out with weekly farm walks and my mum who kindly helped with editing.

A big thank you must also go the way of brothers Mark and Paul Brown for the complete use of daily milking data, allowing us to do a weekly farm walk, and cooperating with data recording. GPS devices used in this study were provided by Massey University and I am grateful for the use of these.

Lastly I would like the pay thanks to my beautiful wife Kate for the love and support I received throughout this project, during a very busy period in our personal lives.

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List of Abbreviations

DGPS	Differential correction global positioning system
GPS	Global positioning system
Fix	Location fix by GPS, whereby the GPS finds its location
R95/CEP	Radius 95%/Circular error probable
SA	Selective availability
EID	Electronic Identification
ha	Hectare
HA	Herbage accumulation
kg	Kilograms
t	Tonnes
DM	Dry matter
MS	Milksolids (Fat + Protein)
MJ ME	Mega Joules of Metabolisable Energy
SCC	Somatic cell count
BW	Breeding worth
PW	Production worth
NDVI	Normalised difference vegetation indices
PGSUS	Pasture growth simulation using smalltalk
WFM	Whole farm model
RPM	Rising Plate Meter
Main herd	Cows that produce milk towards the milk vat
Dry cows	Cows that are in the main herd but are not lactating
Herd 3	Cows that are producing colostrum milk or require special treatment

Chapter 1: Introduction

Dairy farms throughout New Zealand are becoming more information rich as technology develops. Survey results from 530 farmers in 2008 that looked at in-shed information gathering technologies, indicated that 7% of dairy farms in New Zealand have electronic identification systems (EID) in place; 3% have in-line milk meters; 4% have automatic stock weigh scales and 4% have a drafting system (Cuthbert, 2008). This survey was recently repeated and Cuthbert (2013) reported increases in the level of technology adoption. Numbers increased to 37% using electronic identification systems and 15% for drafting systems, while automatic stock weigh scales and in-line milk meters had no significant change (3% and 4% respectively). Additionally, the survey asked farmers what technology they would like to obtain in the future, with a further 11% saying they wanted in-line milk meters, 11% wanted stock weigh scales and 42% wanted a drafting system. Clearly dairy farming is rapidly moving into a more technologically advanced system. As these technologies advance and more farmers begin to incorporate them, especially in new units being built, it creates opportunities to automate and streamline more processes that take place on a dairy farm.

Data collected by devices installed in dairies are being used to provide information about the cows in order to improve production and animal costs (e.g. lameness detection, mastitis detection, individual feeding) and to save on labour costs (e.g. automatic drafting, cup removers and teat spray). However, much of the data being collected by computer technology is still unexploited. It remains important to continue to explore further opportunities for more creative uses of this data as it is a readily available resource that is becoming common on more dairy farms in New Zealand each year.

The majority of farmers lack information about their paddocks, and so a performance measure using the data already being collected in dairies was considered a potential resource to measuring paddock performance. In 2006 just 20% of dairy farmers regularly assessed pasture covers because it was considered boring, or too labour intensive (Clark et al., 2006). Theoretically this means even less farmers are actually using this data to calculate the top performing paddocks and the poorest performing paddocks on the farm. With annual pasture growth between paddocks on a farm varying above 100% difference (Clark et al., 2010), it serves that high performing paddocks will have more pasture eaten, more milk produced due to more grazing events, and higher quality pasture over poor performing paddocks. Dairy farmers may have an educated idea of what they believe is their top and bottom performing paddock, however without any measurement, this ‘feeling’ is never proven. This is the situation on most dairy farms around New Zealand even though pasture is New Zealand’s cheapest feed source and a key driver of production. By managing pasture to a high level and growing more from the poorer performing paddocks, farm profitability can be lifted, by feeding the cows more or reducing the supplement costs. Lifting the average amount of pasture grown each year can substantially increase farm operating profits. For example, an Upper North Island farm can lift farm operating profit by up to \$354 ha^{-1} for every extra 1t DM ha^{-1} grown (Chapman et al., 2012, DairyNZ, 2013). This equates to a 100 ha farm in the Upper North Island currently growing a modest 13t DM ha^{-1}, potentially increasing farm operating profit by \$35,000 if average pasture growth is increased to 14t DM ha^{-1}.

Alternative methods of measuring pasture growth have been developed so that farmers are not required to manually walk the farm on regular occurrences with varying degrees of success. One method is determining the reflectance of pasture with the use of satellites and equating the reflectance to actual pasture covers (Clark et al., 2006). However this was not applicable while cloud obscured the ground and therefore gaps in the pasture growth recording were unavoidable. Devices attached to motor bikes have been developed; however, even with the reduced labour intensity of the work, the majority of farmers have been slow to incorporate these into their management systems. While measuring pasture growth normally requires manual labour or costly instruments, the proposed method uses technology used in a growing number of dairies and incorporates the use of Global Positioning System (GPS) to track cows.

GPS technology is an essential component of many precision agriculture applications. In Australia, research surrounding GPS tracking technology is used to develop methods for managing cattle on large properties. Trotter (2010), Trotter and Lamb (2008) and Trotter et al. (2010) have fitted collars to cattle with GPS units attached, in order to record cattle movement and grazing selection on the large paddocks common on Australian farms. All three studies have publicised that GPS tracking of cattle is possible and also beneficial as a means of identifying where to install fences, determining the optimal size of paddocks and the best place to have water sources. In New Zealand, Draganova (2012) successfully used GPS to help investigate the distribution of urination events by rotationally grazed dairy cows. Similarly, Betteridge et al. (2010b) used GPS along with urine sensors to map cattle and sheep urination patches. With mounting evidence supporting the feasibility of tracking livestock, GPS was then considered as a possible tool to help automate data collection of which paddocks are grazed each day. Furthermore it could then be used as a data feed for other programs such as pasture growth models that rely on paddock grazing event data.

It has been identified that there is a growing amount of data being autonomously collected in modern dairies across New Zealand (Cuthbert, 2013). Furthermore, there are a limited proportion of farmers regularly measuring their pastures, and therefore reducing the overall accuracy of decision making around pasture management in the short, medium and long term. Logically, paddocks that grow more grass will be grazed more and produce more milk. Changes to milk yield and composition are reported to occur from; four hours to 36 hours after feeding or not feeding (Bartsch et al., 1981, Blaser, 1982, Delagarde et al., 2010, Mackenzie et al., 1980, Sheahan et al., 2013). Changes to the AM and PM feeding levels offered by each paddock may then be represented at the subsequent milkings. Therefore the hypothesis is that annual paddock performance can be determined by using milk production and grazing event data. Strong linear regression relationships ($r > 0.75$) will be required between paddock herbage accumulation and milk yield, and paddock herbage accumulation and the number of grazing events. This thesis describes the process of events in taking this data and using it to improve the long term pasture management decisions on New Zealand dairy farms.

Chapter 2: Review of Literature

Economic values for changes in average pasture growth

Farms in the New Zealand dairy industry are predominantly pasture based systems. It is important that farmers manage their pasture in a way that maximises growth and utilisation. A set of decision rules (Macdonald and Penno, 1998) and regular recording of pasture covers are vital to achieve strong pasture growth and utilisation.

Despite sound evidence to support measurement and monitoring practices of pasture, the majority of farms in New Zealand do not routinely collect pasture data (Clark et al., 2006). When pasture is not regularly monitored, feed budgets are not created to manage pasture in the short and medium term (e.g. choosing which paddock to graze, setting rotation length), and therefore no data is collected to measure overall performance across a season (e.g. annual herbage accumulation). The most plausible reason that regular monitoring does not take place on farms is because of the time and effort required. Farmers may believe their time is better spent on other facets of farming. Regular pasture monitoring should lead to better pasture management and therefore increased pasture utilisation and growth. Additionally, it enables an annual performance measure of all the paddocks on farm, again contributing to increased pasture growth because decisions around regrassing are based on pasture growth data, not judgement decisions that may see a paddock regrassed that was not the poorest performing paddock.

DairyNZ's Forage Value Index has calculated an economic value for every extra 1kg DM ha^{-1} grown (Chapman et al., 2012, DairyNZ, 2013). These figures take increased revenue and increased expenses into consideration when varying amounts of pasture is grown. New Zealand is broken into four regions and then split into five seasons with some seasons representing two months and some representing three months (Table 1).

Table 1: Economic value for every 1kg DM ha^{-1} grown for region and season.

	Upper North Island	Lower North Island	Upper South Island	Lower South Island
Winter EV	$0.29	$0.37	$0.43	$0.39
Early Spring EV	$0.46	$0.46	$0.40	$0.44
Late Spring EV	$0.19	$0.15	$0.29	$0.22
Summer EV	$0.39	$0.32	$0.16	$0.10
Autumn EV	$0.40	$0.31	$0.28	$0.25
Weighted average	$0.35	$0.32	$0.30	$0.26

A weighted average has been calculated for each region and applied to changes in average pasture growth per annum (Table 2). A zero change in average pasture growth results in zero dollars change in operating profit. Increasing grass growth by 1t DM ha^{-1} on an Upper North Island farm will potentially increase farm operating profit by $354 ha^{-1}. This equates to a 100 ha farm in the Upper North Island currently growing a modest 13t DM ha^{-1}, potentially increasing farm operating profit by $35,000 if average pasture growth is increased to 14t DM ha^{-1}. Similarly, a 100ha farm in the Lower South Island could increase farm operating profit by $26,000 by increasing pasture grown by 1t DM ha^{-1}.

Table 2: Change in profit ha^{-1} for each region as pasture growth changes.

	Change in average growth (t DM ha^{-1}) per annum			
	-1	0	1	2
Upper North Island	-$354.17	0	$354.17	$708.33
Lower North Island	-$320.83	0	$320.83	$641.67
Upper South Island	-$296.67	0	$296.67	$593.33
Lower South Island	-$262.50	0	$262.50	$525.00

Clearly there is potential to increase farm operating profit by large amounts through focusing on pasture management and increasing pasture grown. A case study on Niaruo Dairies (Lawrence, 2013), Taranaki, highlights the potential savings of improving pasture management. Through measuring pasture regularly, short term management improved, the correct paddocks were regrassed each season and the fertiliser was only applied to portions of the farm that needed it after conducting soil tests. Consequently, this increased pasture growth from 14.54t DM ha^{-1} to 15.53t DM ha^{-1} between the 2008/09 and 2009/10 seasons and increased production by 13,000kg MS. Using the calculated potential farm operating profit increase from the FVI figures, about \$320 ha^{-1} could have been achieved. The case study does not detail operating profits, however it does detail savings made in fertiliser costs. Fertiliser savings alone equated to \$151 ha^{-1} for that year, which suggests an increase in operating profit of \$320 ha^{-1} was probably achieved once increased revenue is considered and added to the fertiliser savings. From the season 2008/09 to the season 2011/12, pasture growth increased from 14.54t DM ha^{-1} to 18.68t DM ha^{-1}. This increase has potentially increased farm operating profit by \$1,325 ha^{-1}, equating to an approximate compounding increase of \$441 ha^{-1} each year.

Methods for measuring paddock performance

Technology has enabled the measurement of pasture covers to be calculated by a variety of tools. Dalley et al. (2009) evaluated different measurement tools and their sutability which are displayed in Table 3. Methods of pasture cover assessment range from no technology required (visual assessments) through to sophisticated technology with measurements from Earth orbiting multi spectral satellite imaging.

Table 3: Evaluation rankings for current and developing pasture assessment techniques. (Dalley et al., 2009)

	Rising plate meter	Visual (calibrated)	Laneway drive by	Sward stick	Rapid pasture meter	Automatic pasture reader	Spectral satellite	Radar
Speed	✓	✓	✓✓✓	✓	✓✓	✓✓	?	?
Ease of use	✓✓	✓✓	✓✓✓	✓✓	✓✓✓	✓✓	?	?
Accuracy	✓✓	✓✓	×	✓✓	✓✓	?	✓	✓
Ability to calibrate	✓✓	✓✓	×	✓✓	✓✓	?	✓	✓
Representative of paddock	✓	✓	×	✓	✓✓✓	✓✓	✓✓✓	✓✓✓
Cost	✓	✓	NA	✓	✓✓	✓✓	?	?
Insensitivity to weather	✓	✓✓	✓✓	✓	✓✓✓	?	✓	✓✓✓
Consistency between operators	✓	✓	✓	✓✓	✓✓✓	✓✓✓	NA	NA
Portability	✓✓✓	✓✓✓	×	✓✓✓	✓✓	✓✓	?	?
Pasture friendly	✓✓	✓✓	✓✓	✓✓	✓	✓	✓✓✓	✓✓✓
Hazard rating	✓	✓	✓✓✓	✓	✓✓	✓✓	NA	NA

✓Low ✓✓Medium ✓✓✓High × Not suitable ? Currently unknown NA Not Applicable

Visual Estimation – The most common method of pasture assessment on New Zealand dairy farms is a visual assessment due to its simpilicty and time efficiency. Visual scoring can be a highly accurate method of estimating the herbage mass in each paddock (R^2 > 0.80) (L'Huillier and Thomson, 1988). This method does however require regular visual calibrations.

Regular calibration of visual estimates is required to ensure the estimation is at an acceptable level. At DairyNZ's Scott farm where weekly pasture walks are conducted, calibrations are also conducted from visual scores of standing pasture. The visual scores are calibrated with 10 x 0.2 m^2 quadrat cuts (4 post-grazing and 6 pre-grazing) to ground level, with cut material washed, dried and weighed. The weight of the dried material is regressed against visual scores for the cut quadrats and a linear regression derived. The regression is then applied to the visual scores for each paddock and the corrected value used to give average herbage mass. This method of calibration however is not carried out by farmers due to its impracticalities, which therefore introduces a level of innaccuracy to the estimates. This can mean farmers may be over or under estimating pasture covers. A possible option for farmers is to occasionaly calibrate their eye to estimates by a rising plate meter or similar.

Rising Plate Meter – The Rising Plate Meter (RPM) measures the average compressed height (5.0kg m^{-2}) of the pasture across a paddock to the nearest half centimetre (1 click) when at least 50 measurements are taken (Stockdale and Kelly, 1984). Table 4 summarises previous studies calibrating RPM's to ryegrass. Correlation coefficients above 0.8 have been reported, for example O'Donovan et al. (2002b), L'Huillier and Thomson (1988) and Stockdale and Kelly (1984) all reported R^2 = 0.87, 0.84 and 0.97, respectivly. For farmers, formulas have been constructed for every month of the year to better match the changing quality and dry matter (DM) content of the grass. The RPM however is labour intensive as every paddock must be walked across, leading farmers to brush off the farm walk when time is restricted, which contributes to the low level of farms currently monitoring pasture.

Table 4: Summary table of yield calibrations from the rising plate meter.

Location	Reference	Species	Period	Equation	R^2	n	Std error
Australia, VIC	Stockdale and Kelly (1984)	Ryegrass/WC	Short term		0.97[2]	8	495
New Zealand	L'Huillier and Thomson (1988)	Ryegrass/WC	Full season		0.86	220	390
			Winter, early spring	125x + 640			
			Late spring, early summer	130x + 990			
			Mid-summer	165x + 1460			
			Early autumn	159x + 1180			
			Late autumn	157x + 970			
Ireland	O'Donovan et al. (2002b)	Ryegrass	Spring, summer, autumn		0.88		318
New Zealand	Roche et al. (2005)	Ryegrass/WC	Winter	156.7x + 945.4	0.69	315	
New Zealand	Roche (2007)	Ryegrass/WC	Winter	149.1x + 785.1[1]	0.75	457	805
New Zealand	Roche et al. (2010)	Ryegrass/WC	Winter, early spring	142.3x + 646.8[1]	0.80	552	775

[1]Multiplier converted from cm in journal paper to RPM height (half cm)
[2]Multiple R^2
WC white clover

Sward Stick – A similar method of measuring pasture covers is carried out by using a sward stick. A sward stick has a plate moving down a rod just like the RPM, however the sward stick measures the standing height of the pasture, not a compressed height (O'Donovan et al., 2002b). The canopy height of the pasture is measured and a simple linear equation can then be fitted to the data to obtain kg DM values. Research by O'Donovan et al. (2002b) and L'Huillier and Thomson (1988) recorded mean correlation coefficients of R^2 = 0.87 and 0.81, respectivly when measuring pastures. This method has had limited farmer uptake, probably due to the labour intensive nature of the measuring method.

Capacitance Probe – Electric capacitance pasture probes such as the GrassMasterII (Novel Ways ltd, Hamilton NZ) have been used for the past few decades. The GrassMasterII emits 5 Volt oscillation signals to the ground and the area surrounding the rod (Serrano et al., 2011). The probe produces an electric field and the surrounding herbage alters this electric field. Herbage mass is calculated by taking a reading of the surronding air and subtracting the average electric field vaules recorded from the herbage. A linear formula can then be applied to the data and produce kg DM values. Trial work using electric capacitance probes have produced strong correlations with O'Donovan et al. (2002b) acquiring an R^2 = 0. 72, Stockdale and Kelly (1984) obtained an R^2 = 0.94 on post grazing measurements and 0.97 on pre grazing measruements. Further more L'Huillier and Thomson (1988) gained a correlation R^2 = 0.86.

Basic method summary – The RPM, sward stick and capacitance probe are all similarly labour intensive and have failed to encourage the majority of farmers to measure pasture covers routinely. The four methods discussed so far are at the basic level and are the most common methods carried out by farmers. Their accuracy is sufficent for farmers needs however use of them is time consuming or, in the case of the visual estimates; being labour friendly and accuracy poor. As technology changes and farm sizes grow, it is becoming increasingly common to have technologically advanced meters to measure pasture covers that are more labour efficient, however these are usually costly.

Technologically advanced methods – Some of the higher cost initiatives (reletive to a RPM) involve using light interception on a sled which is towed behind a motor bike (C-Dax™ pasture meter) to increase the speed and accuracy of pasture cover assesment over the RPM (Lawrence et al., 2007, Yule et al., 2010a). Speeds up to 20km h^{-1} can be achieved as it measures 200 times per second (Dalley et al., 2009). This further enables farmers to map their pasture cover in a paddock rather than just an average figure.

Remote sensing research trials using multispectral images from space to create normalised difference vegetation indices (NDVI) in order to estimate pasture growth and pasture cover on farms in New Zealand have been tested (Clark et al., 2006, Kawamura et al., 2006, Mata et al., 2007). It is apparent it is possible to estimate pasture covers, however the quality of data is restricted by the spectral and spatial resolution of the images used. Clark et al. (2006) and Mata et al. (2007) used images from the satellite SPOT 5 which has a spatial resolution of 10m. Correlations between NDVI and pasture covers with SPOT 5 images can be as high as $R^2 = 0.85$ (Clark et al., 2006) but is generally around $R^2 = 0.60$ (Mata et al., 2007). Frequency of clear images suitable for estimating pasture cover is imperative, and in New Zealand cloud obstructing clear images is frequent and therefore renders this method difficult, as clear images cannot be obtained at regular enough intervals.

Models – Models have been developed to predict pasture growth and cover based on previous paddock data and current climate data. Pasture Growth Simulation Using Smalltalk (PGSUS) was developed to reduce the number of farm walks required. PGSUS is designed to accurately predict the weeks that farm walks are not completed by modeling the pasture covers (Romera et al., 2010). PGSUS can also 'learn' individual paddock's performance based on data loaded the by farm walks that are carried out, meaning the longer PGSUS is used the more accurate it becomes at predicting pasture covers and growth rates. This model was previously used in a prototype stage and recently, it was tested and evaluated by farmers (Romera et al., 2013). Conclusions were it was effective at predicting pasture covers to similar levels as the RPM and farmers thought it showed a lot of promise. However inputting accurate up to date data was the leading reason some farmers were unable to get the best performance the model had to offer.

Summary – The above are able to produce regular information regarding the pasture cover of each paddock measured. Based on these regular readings, the pasture accumulation over a season can be calculated and a performance value given to each paddock, identifying a ranking of paddocks from best to worst. However these methods all require some form of labour in a world that is becoming more automated, much like the data collection now occuring in dairies. Further, there is currently a clear lack of pasture measuring and calculation of paddock performance taking place on New Zealand dairy farms. Through regular pasture measurements, pasture management is improved with information being used to create better decision making. With such conclusive evidence to support regular pasture measurement, farmers are still reluctant to partake in the procedure. Creating an automated weekly farm pasture assessment is difficult; however it may be possible to create an automated summary of paddock performance on a seasonal basis through data being collected by sensor technologies in modern dairies. Paddock performance is one benefit of regular pasture measurement, which helps lead to informed regrassing management decisions, further leading to increased pasture growth.

Current level of technology in dairies

Dairy farms throughout New Zealand are becoming more information rich as technology develops. A survey of 530 farmers in 2008 (Cuthbert, 2008) was repeated in 2013 (Cuthbert, 2013) and reported large increases in farmer adoption of technology in dairies and a growing technology wish list by farmers.

As technology advances and more farmers begin to incorporate it within their practice, it builds opportunities to automate and streamline more processes that take place on a dairy farm. Information technologies in dairies automatically gather information about individual cows. With this information the farmer has data surrounding; how many steps each cow has taken, her weight, milk production, milk flow rate, the electric conductivity of her milk and the position in the herd in which she was milked. This provides a bank of information about the cows that enables automatic detections to be put in place, and provides an opportunity to exploit each cow's milk yield potential. The automated detections and exploiting of cow's potential, improves overall production, saves on labour costs and reduces animal health costs.

To improve production, some farmers now exploit each cow's potential milk production by feeding every cow a calculated mixture of feed. Each cow's feed allocation is calculated through her genetics and her current milk yields which are recorded at each milking. This directs expensive feed to animals that will provide the best response and minimise wastage.

Changes in cow milking order, daily steps, weight and milk yield data can all be used together to identify lame cows (Kamphuis et al., 2013, Van Hertem et al., 2013). Lameness events in cows can be identified earlier than human observation and therefore potentially reduce the recovery time of the animal and the need for drug use.

Similarly, heat detection systems use the same data as lameness detection systems and these data are being collected automatically by an increasing number of farms (Kamphuis et al., 2012). Kamphuis et al. (2012) also state however, that improvements are required in this field in order to achieve an acceptable alert rate of true on heat cows. There may be potential to improve these alerts with more studies. If improvements can be reached, large New Zealand dairy farms with low heat detection rates would benefit the most, through improved in-calf rates, which consequently saves the farm money.

Changes in the electrical conductivity of milk and raised somatic cell counts (SCC) can be indicators of potential mastitis (Kamphuis et al., 2008). Alerts can be set up to report cows that have a raised SCC or changes in their electrical conductivity. For large dairy herds in New Zealand, milking duration is significantly extended when stripping each quarter of the udder looking for signs of mastitis. This takes place when farmers are trying to keep on top of mastitis or find a cow in the herd that does have mastitis. Alerts for cows that potentially have an infection will improve detection rates, the quality of milk and cow health. Furthermore it will improve labour efficiency by reducing the need to strip individual udder quarters.

These are a few examples of the potential features now available in dairies, however there is still room to exploit these data further. All of the current uses for this technology relate to the cows, however milk solid production from cows in New Zealand pasture based milking systems is driven by the ability to maximise pasture growth and pasture harvested (Macdonald and Penno, 1998). Given the large number of paddocks on dairy farms in New Zealand, and their highly variable capability to grow pasture (Clark et al., 2010), it is surprising that the animal production data being captured in the dairies is not being utilised to provide information on what is largely driving their production.

Paddock variability within farms

Paddock performance within a farm varies to a large extent (Chapman et al., 2011). The Lincoln University Dairy Farm (LUDF) consistently records a difference of more than 65% herbage accumulation (kg DM ha^{-1}) between the highest and lowest producing paddocks (Lincoln University Dairy Farm, 2007, 2009). Data collected from DairyNZ's Scott farm has revealed up to an 61% difference in herbage accumulation between the highest and lowest producing paddocks (Clark et al., 2010). Moreover, the same study reported a difference between the top and bottom yielding paddock on a commercial farm was 119%, and at DairyNZ's Dairy No.2 dairy between 1998 and 2001 the difference was 122%. Farmers that do not regularly assess pasture covers will have a belief of what their top and bottom performing paddocks are, but are likely unaware that the difference between the top and bottom paddock, in terms of herbage accumulation can exceed 100%. Paddock variability is obvious when it is calculated using data collected, however visually it can be hard to determine a true difference when 'gut feeling' is used. Consequently, this can lead to paddocks being regrassed that are not the most in need. If the only paddocks that were regrassed each year were the worst performing paddocks, overall average herbage accumulation on farms would increase more dramatically and therefore increase the response rate of dollars spent per increased kg DM ha^{-1} grown.

With a large annual difference between the top and bottom yielding paddocks, it would be expected that the mean historic annual yield and last season's annual yield would have a good correlation. Contrary to this were the results in Clark et al. (2010) where the relationship within farms between each paddock's historic and last season yields were weak, with $R^2 = 0.1$ or less. Clark et al. (2010) and Blackmore et al. (2003) argue the reason behind this may be due to the interaction between the soil and weather conditions each year. The consequences of this result are; paddock soil type and weather conditions across the season must be considered when assessing paddock performance.

Counting paddock grazing events

An accurate record of how many times a paddock is grazed in a season and how many cows grazed it is seldom used as a way of measuring a paddock's performance. Lincoln University Dairy Farm (Lincoln University Dairy Farm, 2007, 2009) keeps this record and over a season or more, a performance observation can be made by analysing the number of cow grazing events each paddock has endured. Higher cow grazing events per hectare represent more pasture grown, as the herd entered these paddocks more often. In addition, recording such data enables an estimate of how each paddock on the farm is performing through back calculating the estimated pasture eaten.

Calculating pasture harvested

There are two methods for calculating pasture eaten. The first method is the disappearance method which uses pasture cover records from regular farm walks. Based on the disappearing pasture after the cows have grazed each paddock, an estimate of the amount of pasture eaten can be derived. An accurate measure requires measuring the paddock the day cows enter as a pre grazing pasture cover, and then again after they leave the paddock to gain a post grazing pasture cover. The difference between pre and post grazing pasture covers is how much pasture was eaten. However this is not always a practical method and usually pasture is measured in every paddock once per week. As there is potential for seven days of growth between when it was measured and when the cows were in the paddock, a less accurate estimate of pasture disappearance is gained.

The second method for calculating pasture eaten is by back calculating how much pasture must have been eaten given the milk production. The energy requirements for dairy cows, measured as units of mega joules of metabolisable energy (MJ ME) are well documented (Holmes et al., 2002a, f, Nicol and Brookes, 2007). The MJ ME required for maintenance, live weight gain and loss, pregnancy, walking and milk production can be calculated through a series of equations and assumptions. Using the available equations and recognised information about milk production and live weight etc., the total intake of energy required for each animal can be estimated. Using known figures of supplements fed each day and the energy content of these supplements, the difference between the estimated total MJ ME intake required and the MJ ME supplied through supplements can be attributed to pasture eaten. Therefore:

$$MJME\ past = Tot\ MJME\ req - MJME\ sup$$

Where:		
	past	Pasture
	Tot req	Total required
	sup	Supplement
	Total required	Activity on tracks (not in paddock), milk production, live weight, stage of pregnancy and maintenance

Milk Production

Attributing milk to paddocks – Pasture growth is the cheapest form of feed for milk production on New Zealand dairy farms. Growing more pasture enables more milk to be produced. Pasture growth from each paddock is measured by farmers through their own opinion or through a calculated procedure of regularly walking/driving the farm measuring pasture covers with a tool such as the RPM. As farmers are paid by milk solid production and not pasture growth, it is surprising there is no performance measure on paddocks for how much milk they produce, especially given the large number of paddocks on farms and the known large variation of pasture production between these paddocks within a farm (Clark et al., 2010).

Attributing milk production from a herd of cows to the paddock they have grazed does not appear to be covered in any literature. This may be due to a couple of reasons, such as: it has never been considered or; it has been considered, however it was decided milk yields would be too consistent day to day in order to show any differences between paddocks, or further, there is not enough knowledge surrounding the time it takes cows to turn pasture eaten into milk. The effect feeding and intake has on milk production is well studied (Broster et al., 1969, Burke et al., 2010, Le Du et al., 1979, Macdonald et al., 2001), likewise information surrounding the processes occurring in the cow for the udder to produce milk (Holmes et al., 2002b, c, g). Putting these two features together, it is surprising there is no direct literature surrounding how long it takes for the cow to turn pasture into milk. More so, without this literature, it is difficult to attribute milk to paddocks.

Time for pasture eaten to be harvested from a cow as milk – The rate at which milk is produced in the udder is fairly well documented (Molenar et al., 2012, Ouweltjes, 1998). However, the time it takes for the feed eaten to be synthesised into that milk is not well known. Anecdotal debates occur when arguing how long it takes for feed to move through the cow's body and be harvested as milk. Arguably the answer has been solved in a recent study by Sheahan et al. (2013), who investigated the effect the timing of supplement feeding has on milk production from pasture fed dairy cows. It took between 12 and 24 hours for the extra feed fed as supplements to be synthesised into extra milk. The extra milk was measured at the 24th hour after feeding. For example cows fed supplement in the afternoon had increased milk yields in the afternoon over cows that did not receive supplement. This result was repeated for cows fed supplement at the morning milking.

Other less-direct studies have investigated offering long periods of pasture allocation to cows and their milk yield response to this. Blaser (1982) gave cows a new block of pasture roughly every 7-9 days. Milk production took one day to respond to the new pasture and two to three days for a peak in milk production to occur. This result is consistent with Delagarde et al. (2010), who rotationally grazed cows in paddocks for >7 days per paddock. Milk yield peaked one day after peak dry matter intake and the percentage decline in milk yield (-25%) matched that of pasture intake (-30%). A study by Bartsch et al. (1981) had cows milked every 3 hours and some fed every three hours while others were fed nothing. The milking at 9 hours detected a significant difference in milk yield between the two treatments which suggests a reduction of milk yield in the udder begins to take place between the 6th and 9th hour of not being fed.

Milk composition rather than milk yield may answer when the cow begins to increase the rate of milk being synthesised as a response to feeding. Within hours of consuming feed, the freezing point of the milk begins to change (Mackenzie et al., 1980). The freezing point of milk falls after feeding because the concentration of salts and products of digestion are high in the digestive tract and blood (Holmes et al., 2002g). A period of fasting sees a fall of protein concentration levels and proportions of C_4 to C_{16} fatty acids increase while C_{18} to $C_{18:1}$ proportions increase (Bartsch et al., 1981).

Concluding, the time it takes for feed to process through the cow's digestive system and provide the energy required to support milk synthesis is difficult to determine. It appears that feed restriction trials detect changes in milk yield faster than trials that increase intake levels though supplementation. Moreover, current literature suggests changes in milk yield can be detected between four (Mackenzie et al., 1980) and 24 hours (Sheahan et al., 2013) after feeding/no feeding. The strongest argument is that a lag time of 12 hours occurs for the majority of feed with some synthesis taking place before and after this time period, hence being detected at the 12^{th} hour milking and the 24^{th} hour milking.

Milking split 14/10 vs 12/12 hours – Research demonstrates that cow udder fill rates are faster during the day (L hr^{-1}) than at night, though morning milking has more milk due to the usual longer time period between milkings (Molenar et al., 2012). Different amounts of milk extracted from cows at each milking affects the paddock performance, if being measured on milk produced. If paddocks are dedicated to being night paddocks, then a bias towards the total milk produced by these paddocks will be imposed because of the longer time cows spend in these paddocks. Providing paddocks are not dedicated as day time and night time paddocks, there should be no issues surrounding the split times between each milking.

Cow genetic merit and age effects on milk production – The amount of milk a cow produces is influenced by multiple factors; genes, stage of lactation, nutritional status, milking intervals and many more (Holmes et al., 2002c). The Breeding Worth (BW) and Production Worth (PW) are measures of profitability for cows based on their genetics. High genetic merit cows produce more milk than low genetic merit cows. Furthermore, high genetic merit cows convert pasture into milk more efficiently, so by feeding these animals more food, more milk production can be obtained compared to if more feed was fed to low genetic merit animals. Bryant (1981) compared the milk production of high and low genetic merit animals and reported the difference between high and low genetic merit cows as being 0.35kg MS day^{-1} during the period of the study. The high genetic merit cows had greater feed conversion efficiency, being able to produce on average 14g MS kgDM^{-1} eaten, more than the low genetic merit cows. A more recent study by Woodward et al. (2011) looked at the difference of high and low BW cows. Here it was reported the group with high genetic merits (average BW-198, PW-319) produced 0.30kg MS cow^{-1} day^{-1} more than the low genetic merit cows (average BW-57, PW-10). The high genetic merit cows also converted feed at a rate of 83g MS kgDM^{-1} compared to 70g MS kgDM^{-1} for the low genetic merit cows.

Age and years of lactation can have a large influence on milk production from cows. Providing the cow is healthy, milk production will continue to increase over successive seasons until the animal reaches its fourth or fifth lactation (Holmes et al., 2002f). Latest New Zealand dairy statistics (DairyNZ, 2012) indicate cows aged six years are producing at their peak, which corresponds to cows in their 5th lactation. Cross bred cows aged six years are producing 104 kg MS more than two year olds and 59 kg MS more than 10 year olds. If herds on a farm are split by ages or merit, there may be a bias to the paddocks they graze if they have dedicated paddocks to each herd.

Weather effects on production – Climate is considered a key driver of pasture yield variability. At different periods of the season different aspects of the climate are key drivers. Rainfall and soil moisture are outlined as the most significant factors for summer pasture production by a number of studies (Glassey, 2011, Radcliffe and Baars, 1987, Zhang et al., 2005, Zhang et al., 2006). In the winter, warm weather and sunshine are be key drivers of pasture production (Roche et al., 2009). If the right weather conditions are not present, pasture production slows and if the weather is severe enough, milk yields reduce.

Adverse weather events such as heavy rain, cold winds and high and low temperatures all have short term and long term effects on pasture production and milk production. During very cold adverse weather events which only occur on a small number of days each year in New Zealand, cows expend more energy to ensure they stay warm, therefore reducing the amount of energy directed to milk production (Bryant et al., 2007, Holmes et al., 1978). More commonly in New Zealand, hot and humid weather can have a similar effect, where the cow becomes heat stressed and reduces the level of feed intake for a number of reasons (Bryant et al., 2007, West et al., 2003).

Short term adverse weather events have the potential to reduce milk production for a short period, and thereby reducing milk production assigned to paddocks where the cows had been during the bad weather, if milk per paddock was measured. Long term events however (drought) have long term effects on pasture and milk production thereby causing no unfair bias towards certain paddocks, as most if not all paddocks will be effected in the same way. Depending on soil types responses observed will be different, however this occurs during all types of weather and should be considered when making decisions.

Supplements

The ability of a dairy cow to turn extra feed into milk is dictated by her current energy deficit, the digestibility of the feed and how the feed is partitioned in the body. A high proportion of the extra energy will be transferred into milk synthesis, providing her current production is much less than the potential (Clark and Woodward, 2007, Holmes and Matthews, 2001). Holmes and Matthews (2001) used data from Grainger (1990) and Stockdale and Trigg (1989), to estimate that cows in early lactation with a severe feed shortage will partition 70% of extra feed energy towards extra milk synthesis. Mid lactation cows on a moderate feed shortage will partition

40%, late lactation cows will partition 35%, while a cow on no feed restrictions at all will partition 0% of the feed to extra milk synthesis.

The feed that is not partitioned towards milk must be used in some way by the cow. If the extra energy is not used by the udder, it must be converted to extra live weight gain, however this added weight can be used for better fertility responses and increased milk production (Figure 1) at another time by the mobilisation of body tissue (Holmes and Matthews, 2001).

For lactating cows, any MJ ME consumed by the body, above maintenance requirements, can be partitioned towards either live weight gain or milk synthesis, or both at the same time. When a lactating cow is losing weight, body tissue becomes mobilised and is used to support milk synthesis. According to Holmes et al. (2002d) it is impossible to accurately measure the efficiency at which additional feed is used by the cow for milk synthesis due to partitioning of ME towards the udder or body tissue.

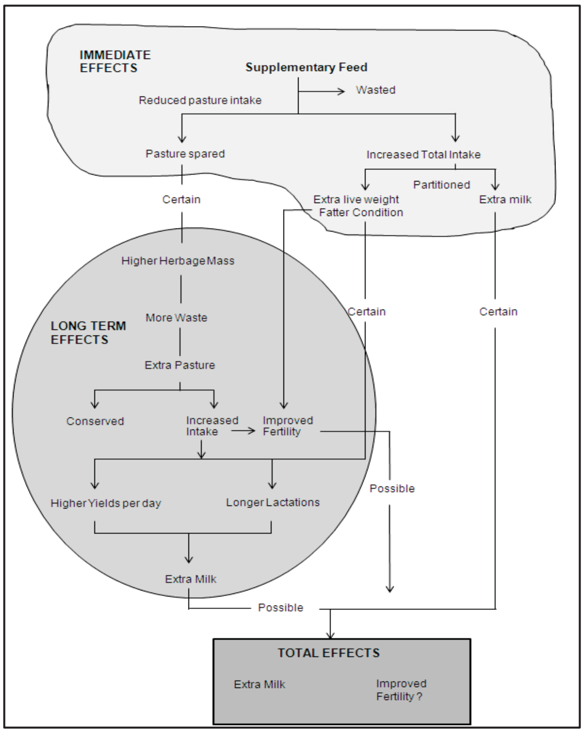

Figure 1: Immediate and long term effects of supplement feeding. (Holmes et al., 2002a).

The substitution of pasture for supplementary feeds is measured as the reduction in pasture intake per kg of supplement DM consumed. Supplements are used for a variety of reasons, such as conserving pasture, increasing milk yields, extending days in lactation and increasing cow condition. It is difficult however to obtain a substitution rate of 0.0 (Holmes et al., 2002e) as the cows will favour the supplement over pasture and therefore causing substitution. A substitution rate of 0.0 means for every 1 kg DM supplement eaten, there was no reduction in the amount of pasture eaten. A rate of 1.0 means for every kg DM supplement eaten, the cows reduced their pasture intake by 1 kg DM. Generally substitution ranges from 0.3-0.7 (Holmes and Matthews, 2001).

The substitution rate is strongly related to the size of the energy deficit the cows currently exert (Table 5). Furthermore, substitution rates are no different throughout lactation providing the size of the energy deficit is similar (Clark and Woodward, 2007, Holmes et al., 2002e). If the energy deficit is different, then this will be the controlling factor for having a different substitution rate at different stages of lactation. However, this differs to the response from supplements, where stage of lactation has an impact on the size of the response because of the dairy cows' potential yield decreasing throughout lactation.

Table 5: Substitution rates for cows fed supplements at different levels of pasture intake.(Grainger and Matthews, 1989).

Supplemented DM intake[1]	Substitution Rate [2]
40	0.1
60	0.4
80	0.7
100	1.0

[1] as a % of *ad libitum* intake
[2] Decreased Pasture Intake (kg DM) / kg Supplement DM intake

Concentrate response – Cows that are producing 2.4 kg MS day^{-1} and are then fed concentrates will potentially increase their MJME intake by 40%, whereas if fed maize silage they will be able to increase the total MJME intake by just 10%. However in large energy deficient cows, maize will increase intake by 85% (Clark and Woodward, 2007). This highlights that when fed concentrates, energy deficient cows increase their intake, which adds value to the product.

Maize Silage response – Maize is more often made into a silage stack or bunker where large quantities of wastage can occur. Feeding crops that are ensiled involve more wastage than the likes of concentrate being fed through the dairy. Wastage at the silage stack is estimated to be in the vicinity of 10-15% on average while good management reduces this to about 5% (Clarke et al., 1988, Thomas and Mathews, 1991). If it is fed to the cows in the paddock wastage can exceed 20% (Holmes and Matthews, 2001). Wastage at 20% will have an effect financially no matter how affordable the feed is. Feeding in concrete feed troughs can reduce the wastage. Maize often produces responses of 40-130g MS $kgDM^{-1}$, however the size of the response depends on the size of the feed deficit at the current time of feeding (Dalley et al., 2005, Macdonald, 1999, Stockdale, 1995).

Pasture silage response – Pasture silage quality is reported to have no influence on intake levels, however quality has an impact on the MS response (Macdonald et al., 2000). Clark (1993) reported feeding 5kg DM of high quality pasture silage per day for 30 days in the spring, summer and autumn gave responses of 26, 16 and 66g MS $kgDM^{-1}$ silage for each season, respectively, which could be classed as mid-high responses.

Chicory response – Feeding chicory as a forage crop over summer months can be useful for dairy production. Milk production from cows supplemented with chicory have similar response rates to those results observed with cows being supplemented with turnips. The milk production and milk solid response from chicory is dependent on the initial pasture allowance. Lower initial pasture allowances allow the cows to have a better response from chicory, compared to those cows fed high initial pasture allowances. Responses range from 28-56g MS $kgDM^{-1}$ offered when cows are fed between 15 and 40kg DM of pasture per day with 4kg DM cow^{-1} day^{-1} offered from chicory (Waugh et al., 1998).

GPS on animals

The system – The Global Positioning System (GPS) is a system that runs off the Navigation by Satellite with Timing and Ranging (NAVSTAR) system and is operated by the U.S. Department of Defence. It is made up of 24 satellites precisely orbiting Earth so that at any point on Earth, at any time of the day, at least five satellites are in the visible sky (Turner et al., 2000). On land, there are a series of stations monitoring satellite information (location, time and health status) to ensure the system is operating correctly (Turner et al., 2000). User GPS devices (such as navigation devices in cars) communicate with the visible satellites in the sky through radio waves, to triangulate their position on Earth as a set of coordinates. Apart from the initial cost of a GPS device and batteries on collar systems, there is no on-going cost to use the GPS system (Turner et al., 2000).

Use of GPS on livestock – Since 1995 there has been rapid growth of research monitoring livestock location and their spatial behaviour through the use of GPS (Agouridis et al., 2004, Betteridge et al., 2010b, Rempel and Rodgers, 1997, Trotter et al., 2010). This increase in research interest may be attributed to the reduction of costs associated with the technology (Trotter et al., 2010) and the improved accuracy of the technology. One fact attributing to these improvements is U.S. Department of defence turning off the Selective Availability (SA) in 2000, which allowed civilians to access, non-degraded positions (Adrados et al., 2002). SA was a tool used by the department of defence that degraded accuracy to civilian users.

The focus of GPS and cattle research varies from, mapping urination events of livestock (Betteridge et al., 2010b), to publications on monitoring grazing and feeding behaviour (Schlecht et al., 2004, Tompkins and Filmer, 2007, Trotter and Lamb, 2008, Turner et al., 2000, Udal et al., 1998). Monitoring livestock positions at regular frequency using GPS has enabled researchers to observe the different behavioural characteristics of the animals in relation to the spatial and temporal environment. These types of data have the potential to have economic benefits as seen with research carried out by Tompkins and Filmer (2007).

In New Zealand, dairy cow tracking with GPS has become an important tool in the move to reduce the amount of nitrogen leaching through urine patches. In the past couple of years there have been numerous publications which investigated urine patches with the use of GPS collars on the cows (Betteridge et al., 2010a, Betteridge et al., 2012, Betteridge et al., 2010b, Yule et al., 2010b). Interestingly there appears to be no use of GPS on dairy cows for reasons other than behaviour research. Presumably this is due to cost and limited understanding outside the research community on the capability of GPS.

Testing and accuracy – Before using GPS on animals it is common to carry out static testing of GPS devices (Ganskopp and Johnson, 2007, Moen et al., 1997, Turner et al., 2000). Static testing provides critical information regarding GPS device's performance in different climatic and topographic conditions. The absolute errors can be expressed as radial distance of error from the true location. Circular error probable (CEP) is a circular radius that contains a stated percentile of points around the true location (Moen et al., 1997, Rempel and Rodgers, 1997, Rempel et al., 1995, Turner et al., 2000). Another name for this is horizontal 95% accuracy (R95) (Agouridis et al., 2004).

The fix rate is a term given to how often the GPS device is programmed to locate its position and is dependent on the type of study. A one hour fix rate means once every hour the GPS will record its position. Some studies require high fix rates to record every movement of the animal while others only need a low fix rate to record where animals are at certain times. Swain et al. (2008) investigated the accuracy surrounding animal location and patch selection area. Their study highlights the need to increase fix rate as patch area decreases in order to accurately predict animal location. Common fix rates range from 10 seconds to one hour for tracking animals.

Some studies cited in this review use differential correction (DGPS) in the analysis of the data to improve their results (Rempel and Rodgers, 1997, Turner et al., 2000). DGPS was more common and needed prior to the SA being turned off during the year 2000. Recent studies (Betteridge et al., 2010b, Draganova, 2012) have not used DGPS as the accuracy of the GPS was sufficient for their study. GPS units are commonly reporting 95% CEP well below 5m (Agouridis et al., 2004, Betteridge et al., 2010b, Trotter and Lamb, 2008) without DGPS which would be sufficient for most location based studies.

Chapter 3: Testing and simulating GPS on dairy cows to record paddock grazing event data

Introduction

Since 1995 there has been rapid growth of research monitoring livestock location and their spatial behaviour through the use of GPS. The focus of GPS use with production animals is centred on mapping urination events of livestock (Betteridge et al., 2010b), and monitoring grazing and feeding behaviour (Schlecht et al., 2004, Tompkins and Filmer, 2007, Trotter and Lamb, 2008, Turner et al., 2000, Udal et al., 1998). Increasing research interest may be attributed to the technology reducing in price (Trotter et al., 2010) and the accuracy improving.

There appears to be no use of GPS technology on dairy cows that is incorporated into the New Zealand dairy farm system. If paddocks that are grazed each day are routinely recorded, the information can be used to identify grazing rotation order, as well as how many times the paddocks were grazed over a season or further. In spite of this, grazing event data is not routinely collected off dairy farms (Clark et al., 2006). Romera et al. (2013) tested the use of a software tool (Pasture Growth Simulation Using Small talk, PGSUS) to estimate herbage mass of individual paddocks on farms. A key conclusion was farmers that tested the software found it useful; however data input by the farmers was sometimes absent and reduced the quality of the output data. Farmers found it difficult keep up to date with the input of grazing event data. Romera et al. (2013) further specified that if the issue of paddock grazing event data entry could be overcome, it was envisaged that a full commercial version of PGSUS would appeal to objective data oreintated farmers. GPS technology could play a vital role in creating a system that could be integrated into the dairy farm system to automate data collection of grazing events.

Before GPS technology could be implemented on the animals, static testing was required to determine the precision and accuracy of each GPS device. Furthermore static testing also provided a large data set for a simulation procedure to take place. The aim of the simulation procedure was to ascertain the equilibrium between cost, battery life and accuracy so future builds of GPS units would need to meet a set of minimum requirements at the lowest possible production cost.

Materials and methods

Static testing – To determine the precision and accuracy of the GPS devices, a large number of co-ordinates were obtained through static conditions in a flat open paddock. These data were tested against a calibrated differential GPS device, called a real-time kinematic global positioning system (RTK – DGPS) with an accuracy of 30mm. Using the RTK – DGPS, a grid of 23 points spaced at 3m apart were marked in a recently grazed paddock and their co-ordinates recorded, giving an exact location of each point (Figure 2).

Figure 2: RTK – GPS setup, GPS static testing, RTK – DGPS rover unit.

The devices were spaced at 3m to ensure they were far enough away to eliminate interference between GPS devices, yet not so far away from each other that a bias from satellite visibility was introduced (Agouridis et al., 2004). One GPS device was placed on each of the points and left for 5 days. To appreciate the effect the fix rate has on the measured accuracy, there were 5 treatment groups of 5 GPS units. The 1 minute setting was when a unit was left recording a position every minute nonstop. The other GPS units were set to be on for 10 minutes then be off for a set time. During this “on period” of 10 minutes they were intended to record 10 positions. Using the 30 min setting for an example, the unit would be on for 10 minutes and off for 20 minutes making a total 30 minute cycle.

Table 6: Treatment groups for the study displayed as minutes between location fixes.

Treatment	Units
1 Minute	5 random units (M1-M5)
15 Minutes	5 random units (M6-M10)
30 Minutes	5 random units (M11-M15)
60 Minutes	5 random units (M16-M20) 3 other units (T1-T3)

Twenty GPS collars designed and built by Massey University were named M1, M2...M20 (Table 6). Three further GPS devices from Telemetry Solutions ltd, USA were purchased. These were named T1, T2, and T3. Units T1-T3 were devices only and were fitted to a general cow collar commonly used on dairy farms in New Zealand. The results from the static testing provided the information required to determine the minimum requirements to build future low cost GPS devices and minimum requirements to accurately report which paddock the cows have grazed, which were obtained through a simulation process.

Simulation – The aim of the simulation was to calculate how many points, per animal, per day were required to correctly identify which paddock a herd of cows were grazing. In order to do this, four variables were applied to different scenarios:

1. High number and low number of GPS units per herd
2. High number and low number of location points per herd
3. Cows that graze close to boundary fences
4. Different paddock sizes and shapes

The simulation was conducted using the statistical package GenStat with default settings as:

Paddock shape:	Rectangle
Paddock size:	100X200m (2ha)
Number of position fixes:	3
Uncertainty zone size:	5m from fence
Start time:	00:00
End time:	24:00
Scale factor:	1

Paddock shape was changed based on the paddock size. Long narrow paddocks have more fence length compared to that of a square paddock that is the same area. Therefore, different paddock shapes and sizes were applied, ranging from 0.56ha to 3.0ha as square and rectangular paddocks. The number of position fixes per day dictates battery life of the GPS units and therefore a range of fix rates were applied, ranging from one to six per day. The uncertainty zone is dependent on the accuracy of the unit and is visualised below in Figure 3. The uncertainty zone represents a zone surrounding the paddock boundary. If a position was taken inside the uncertainty zone, there is uncertainty if it was truly taken in the paddock identified, or the neighbouring paddock. The size of the uncertainty zone was always matched to the accuracy of the units while other variables were being tested, however it also was tested as its own variable with other variables remaining at default. The size of the uncertainty zone ranged from 1m to 12m.

The simulation used the data gained from the poorest and highest performing unit from each treatment group to create a group of four most accurate and four least accurate units. A scaling factor was introduced to gain a larger spread in the data. Scaling of 150% and 200% were applied to the worst performing set of GPS devices to simulate very poor performing devices. Latitude and longitude of three lines of data already collected from the static testing were randomly selected. With these data, distance and direction from true zero were calculated. Then three random positions were simulated in a paddock and the distance and direction from zero applied accordingly. The positions were calculated and assessed to fit in differently labelled parts of the paddock (Figure 3). This process was repeated 30,000 times and the probabilities for each zone of the paddock calculated.

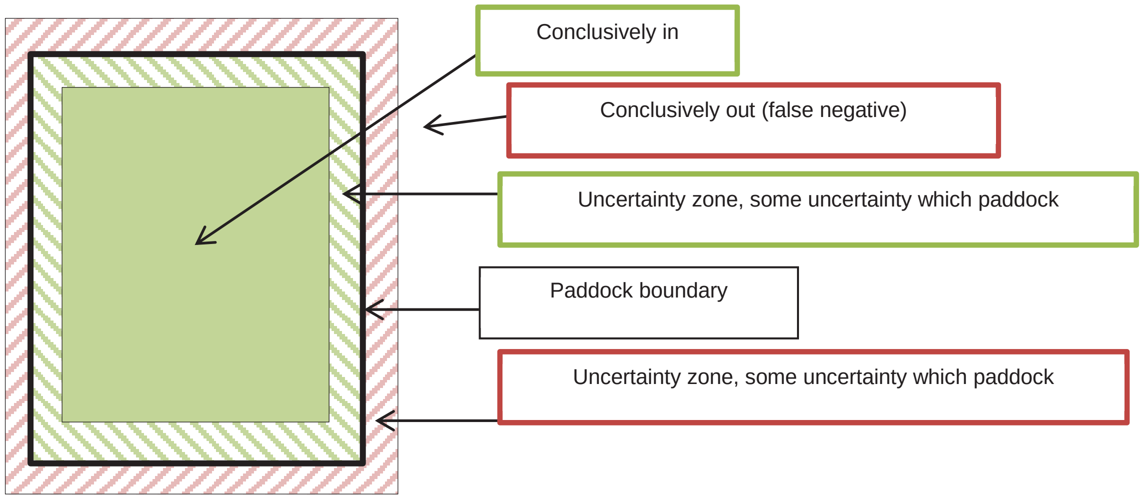

Figure 3: Zones of the paddock used during simulation.

Results

Static testing – After 5 days of recording between the 5th and 11th October 2011, the data was downloaded and the horizontal 95% accuracy (R95) or also known as the 95% Circular Error Probable (CEP) was measured for each unit. Differential correction (DGPS) was not applied to the results as DGPS will not be used when the collars are on the cows. During this period there was a variety of weather conditions including; thick cloud, rain and clear days.

There was no apparent difference in accuracy from a day to day basis. There are however changes in accuracy within each day, due to effects of satellite location in the sky. Figure 4 indicates there was a common trend throughout the day where the accuracy reduced in the afternoon and evening and was best late at night or early morning. There was no association with accuracy and horizontal dilution of precision (HDOP).

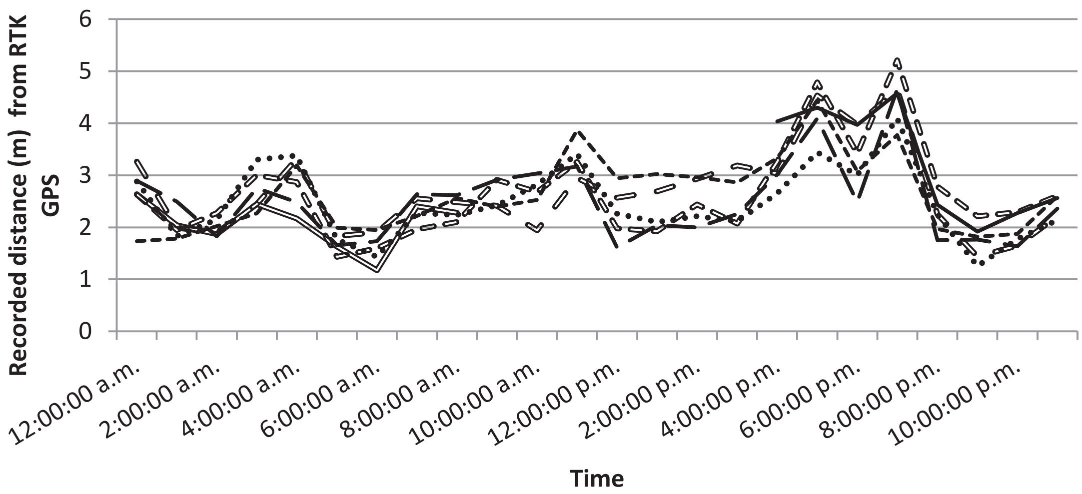

Figure 4: Average accuracy throughout the day using average values from 20 GPS devices.Day 1 (—), Day 2 (= = =), Day 3 (– –), Day 4 (···), Day 5 (= =), Day 6 (— —), Day 7 (===).

The top and bottom performing unit from each treatment group were isolated and used for further investigation. The results displayed in Table 7 indicate no obvious difference in accuracy between the first location fix of a set of 10 and the 10th for both the most accurate and least accurate set of GPS devices.

Table 7: Summary of average accuracy for position fix and time from the four most and four least accurate GPS units.

	Most accurate units											Least accurate units										
Unit	**M4**	**M7**			**M13**			**M18**			**Mean for time**	**M2**	**M8**			**M11**			**M20**			**Mean for time**
Time treatment	**1 min**	**15 min**			**30 min**			**60 min**				**1 min**	**15 min**			**30 min**			**60 min**			
Measurement	**1**	**1**	**2-9**	**10**	**1**	**2-9**	**10**	**1**	**2-9**	**10**		**1**	**1**	**2-9**	**10**	**1**	**2-9**	**10**	**1**	**2-9**	**10**	
00:00 - 02:00	1.77	1.98	2.05	1.99	1.87	1.74	1.75	4.97	1.86	2.01	**2.20**	2.90	2.09	1.91	1.48	1.98	2.07	1.96	2.50	2.13	2.10	**2.11**
02:00 - 04:00	1.87	2.21	2.49	2.50	2.39	2.58	2.82	1.89	2.25	2.33	**2.33**	2.73	2.96	3.43	3.26	2.79	2.98	2.87	4.58	3.52	3.17	**3.23**
04:00 - 06:00	1.79	1.90	1.90	2.33	1.48	1.76	1.89	2.21	1.87	1.69	**1.88**	2.68	2.31	2.73	2.87	1.64	2.14	1.94	2.29	1.65	2.19	**2.24**
06:00 - 08:00	2.62	2.12	2.16	2.31	1.93	2.00	2.10	2.63	2.39	2.49	**2.28**	2.72	2.43	2.61	2.42	1.43	1.60	1.66	2.38	2.15	2.08	**2.15**
08:00 - 10:00	2.10	2.07	2.31	2.39	2.08	1.99	2.11	2.05	2.01	2.11	**2.12**	3.34	2.38	2.54	2.46	2.36	2.63	2.67	2.33	2.41	2.41	**2.55**
10:00 - 12:00	2.63	2.58	2.95	2.84	2.35	2.35	2.53	2.90	3.44	3.52	**2.81**	3.65	2.68	3.06	3.08	2.54	3.01	3.03	2.77	3.13	2.88	**2.98**
12:00 - 14:00	2.80	2.51	2.49	2.51	1.71	1.89	2.06	1.74	1.33	1.52	**2.06**	3.67	2.44	2.57	2.60	2.11	2.38	2.44	2.35	2.17	2.10	**2.48**
14:00 - 16:00	2.20	1.66	1.69	1.68	2.06	1.99	2.04	2.30	1.62	1.49	**1.87**	3.59	3.54	3.88	4.06	2.61	2.64	2.76	2.60	2.96	2.94	**3.16**
16:00 - 18:00	3.85	4.29	4.28	4.40	4.24	4.03	3.78	4.44	4.35	3.89	**4.16**	4.96	3.94	4.01	4.44	4.27	4.09	4.20	3.30	3.56	3.90	**4.07**
18:00 - 20:00	2.98	3.61	3.75	3.91	2.98	2.92	3.10	2.97	2.36	2.31	**3.09**	4.32	3.76	3.95	3.92	3.27	3.44	3.54	4.03	4.46	4.38	**3.91**
20:00 - 22:00	1.16	1.52	1.41	1.39	1.55	1.46	1.43	1.68	1.40	1.63	**1.46**	2.17	2.55	2.63	2.62	1.71	1.71	1.96	2.80	2.67	2.74	**2.36**
22:00 - 00:00	1.58	2.15	2.42	2.36	1.70	1.70	2.21	2.22	2.12	2.00	**2.05**	2.98	2.81	2.67	2.47	2.65	2.65	2.44	2.61	2.62	2.45	**2.64**
Mean for unit	**2.28**	**2.38**	**2.49**	**2.55**	**2.20**	**2.20**	**2.32**	**2.67**	**2.25**	**2.25**		**3.31**	**2.82**	**3.00**	**2.97**	**2.45**	**2.61**	**2.62**	**2.88**	**2.79**	**2.78**	

Sharp error direction changes were detected between fixes during static testing. Figure 5 illustrates these sharp changes. This GPS device was to fix a location once every hour. The lines of the plot follow time and only two days are plotted for ease of viewing. The point 0,0 represents where the GPS actual location was. Figure 4 and Figure 5 illustrate on a day to day basis, the error was similar however the direction in error was changeable and impossible to predict.

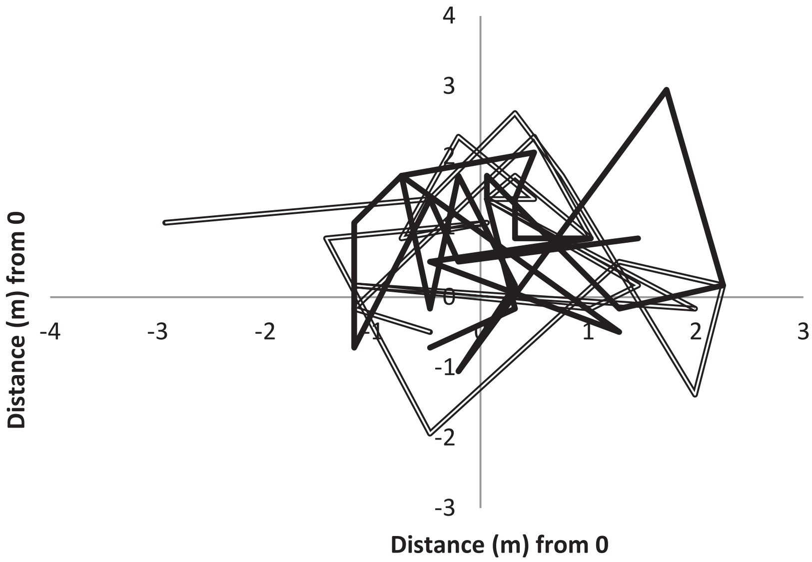

Figure 5: Sample GPS of hourly position across two days. 6/10/12 (===) and 7/10/12 (—).

Simulation – A difference of 0.5m for the 95% circular error probable (CEP) was recorded between the four most accurate units and the four least accurate units. Scaling was applied to the four least accurate units to create a greater spread of accuracy that represented potential cheap units with poor accuracy. Applying a scale of 50% and 100% resulted in 95% CEP's of 8.0m and 11.0m, respectively (Table 8).

Table 8: Measured accuracy of each treatment for the simulation.

	Mean accuracy ± m (SD)	95% CEP
Best 4 units	2.36 (1.39)	5.0
Least accurate 4 units	2.96 (1.37)	5.5
Least accurate 4 units scaled up 1.5 times	4.43 (2.05)	8.0
Least accurate 4 units scaled up 2.0 times	5.92 (2.73)	11.0

When all variables remained at default settings, and positions were taken at every hour throughout the day, there was no difference (<1%) in probabilities of at least one of the three positions correctly identifying the correct paddock when positions were taken at different times of the day.

With just one location fix taken and all other variables at default settings, the potential of that fix being in the conclusive zone of the paddock was roughly 68-86% (Figure 6). When two position fixes were taken, this increased the chances of gaining at least one location fix that conclusively reported which paddock was grazed, to 90%. When three or more positions are taken, a GPS with a CEP of 11m gained at least one of those positions in the conclusive zone more than 95% of the time.

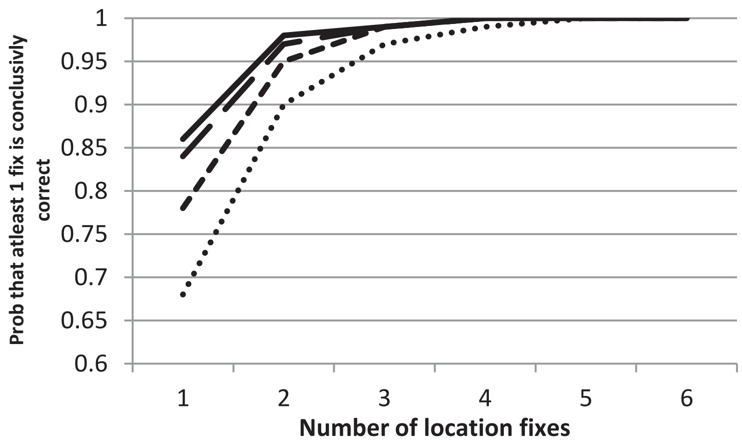

Figure 6: Probabilities of at least 1 fix being conclusive to the correct paddock. CEP 5m (—), 5.5m (− −), 8m (- - -), 11m (···).

Setting the uncertainty zone to 1m when the 95% CEP of the unit is 11m may not be practical and lead to about 13% of the positions being conclusively out (Figure 7). Matching the uncertainty zone to the recorded accuracy of the unit reduced the probability of at least one of the three position fixes conclusively locating the incorrect paddock down to below 2%. Setting the uncertainty zone larger than the recorded accuracy reduced the chances that 1 of the 3 positions conclusively locate the wrong paddock. However in doing so, it also reduced the number of positions ruled conclusively in the correct paddock (Figure 6).

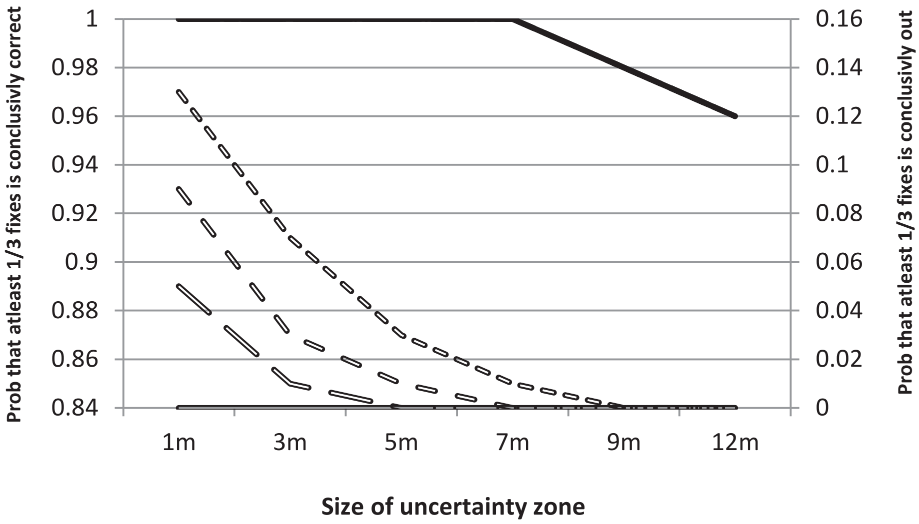

Figure 7: Probabilities of at least 1 out of 3 fixes being conclusive to the correct and incorrect paddock. Conclusive to correct paddock for CEP 5m (—), 5.5m (− −), 8m (- - -), 11m (···) and conclusively out CEP 5m (═══), 5.5m (═ ═ ═), 8m (= = =), 11m (°°°).

A square paddock has a better ratio between fence length and paddock area compared to rectangular paddocks. When the probabilities of a square paddock are compared to those of a rectangle paddock (the ratio of L x W stayed the same as size increased) at the same sizes, differences were observed. With default settings of three position fixes, a unit with a 95% CEP of 11m will have at least one of the three positions confirm the paddock 87% of the time on a 0.56ha square paddock (Figure 8). Whereas a rectangle paddock (110m x 50m) will have at least one of the three positions confirm the paddock 83% of the time (Figure 9). GPS devices with a 95% CEP of 5m will have at least 1 of the 3 positions confirm the correct paddock 98% of the time on a 0.56ha square or rectangular paddock

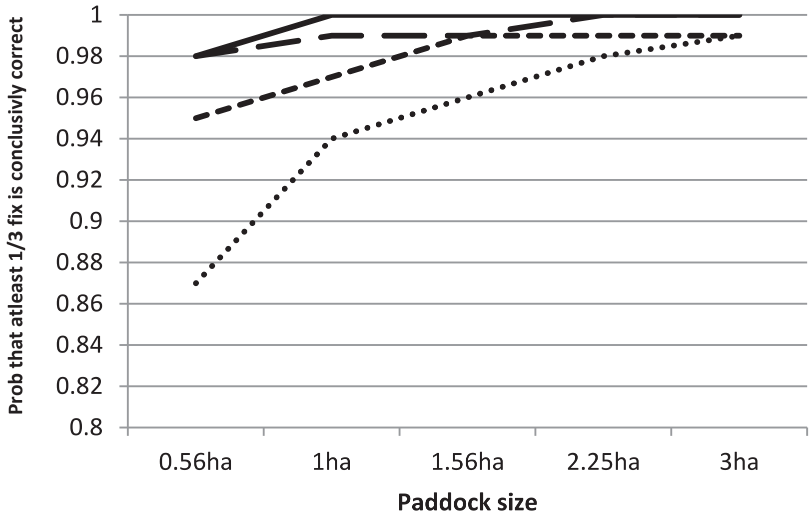

Figure 8: Probabilities of at least 1 out of 3 fixes being conclusive to the correct square paddock. CEP 5m (—), 5.5m (− −), 8m (- - -), 11m (···).

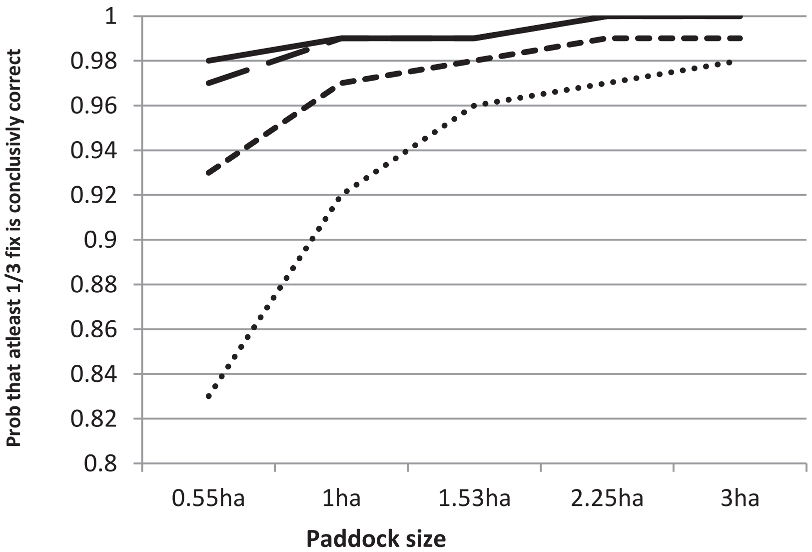

Figure 9: Probabilities of at least 1 out of 3 fixes being conclusive to the correct rectangle paddock. CEP 5m (—), 5.5m (− −), 8m (- - -), 11m (···).

Discussion

Static testing – The units supplied by Massey University were set to take 10 positions over 10 minutes and then be turned off for a set amount of time. The measurements were broken down to first (1), last (10) and anything in between (2-9). This was because sometimes units would miss a position and only record 9 positions or record 11 positions. Draganova (2012) suggested the first measurement in a series of location fixes over a short period of time will be the least accurate and the last measurement of the group will be the most accurate. It is believed that while the GPS device is on, each position it fixes will become more accurate as each new position that is taken, the GPS refines its position. However this is something we did not observe (Table 7). Results indicate that in some cases the best position was the first and the worst position was the last.

A closer look at the daily pattern of accuracy exposed the unpredictable nature of the units as each position was taken. Although the average error each day was very similar on a day to day basis, the direction of this error was changeable. For example Figure 6 highlights the sharp changes in error direction. These results are of a similar nature to those in Taylor et al. (2004) where they reported the pass to pass error, unpredictable.

Simulation – The simulation produced expected results, however there was one result which was not expected. It was originally thought changes in the accuracy across the day that was observed in the static testing would have an effect on the GPS devices ability to locate the correct paddock being grazed by the cows. However the simulation results established that, time of location fix has a minimal effect (<1%).

Paddock size and shape do have an influence on how precisely the GPS devices can locate the correct paddock. Although 0.56ha paddocks are rare on New Zealand dairy farms, the simulation indicated a reduction in accuracy for this sized paddock compared to a 1ha paddock.

This result needs to be considered and applied to the host farm of the GPS devices. The smallest paddock size will need to be known to assist in the decision of how many GPS devices to use. There does need to be at least two units per herd, preferably three. This is for practicality reasons where there is always a chance a cow with a GPS unit may be drafted out of the herd for any reason, or the collar falls off the cow. Furthermore, the more devices that are used the longer the battery life will be as fewer points are required per unit, however every new unit is a large capital cost.

The overall required accuracy of the GPS units is farm dependent. A farm with small paddocks (<1.5ha) will require a 95% CEP of ~6m (+/- 6m). However if the farms average size paddock was >1.5ha the required 95% CEP would increase to ~9m (+/- 9m). Swain et al. (2008) results are in agreement, where they reported a need to increase fix rate as patch area decreases in order to accurately predict animal location. In the case of this study, the same rule applies for accuracy. As area decreases, higher GPS accuracy is required to accurately measure animal location.

To implement this automated method of recording paddock allocation, a system will need to be produced where the data is captured automatically and connected to a digital map of the farm. A probable method of automatically taking the location figure and turning it into a paddock will be the use of the mathematical equation ‘winding number’. This is something that needs to be investigated further, however the platform for the accuracy and settings of GPS devices required to automatically record paddock allocation has been calculated

Conclusion

The use of GPS to locate which paddock a herd of cows graze each day has been tested. To determine the minimum number of GPS units and the fix rate required to accurately record the paddock being grazed by cows, a simulation was carried out to acquire default settings and the requirements from GPS units. A minimum of three GPS units per herd are required to sufficiently record paddocks that are grazed. These units need to have a tested accuracy of no more than +/- 6 metres, 95% of the time (95% CEP 6m) to accurately measure a paddock of 0.5ha and the number of locations fixes required per paddock needs to be at least three.

Chapter 4: Modelling paddock performance using data routinely collected by New Zealand milking systems

Introduction

Dairy farming in New Zealand has an opportunity to increase pasture production and therefore milk production. Large differences between the paddock that grows the greatest amount of pasture and the paddock that grows the least exist. Common differences measured are above 100% (Clark et al., 2010). Pastures in New Zealand however are not regularly measured by most farmers, mainly due to the physical and time consuming nature of the task (Clark et al., 2006). Furthermore, information surrounding when each paddock was grazed can be a struggle for farmers to maintain (Romera et al., 2013). For farmers to identify which paddock is growing the least pasture and therefore needs to undergo pasture renewal or further investigation into its poor performance, regular pasture measurements are required or a record of how often each paddock is grazed over the season. Without any form of performance calculation for each paddock, farmers might regrass paddocks that are not the least productive. Identifying these poor performing paddocks and applying the best solution to increase pasture growth will have a greater increase on average pasture growth across the farm, than if a paddock that is not the worst performing is repaired.

An easier method of ranking each paddock's performance may mean farmers are more likely to use this information in their strategic decision making. In an attempt to create an easier method for ranking paddock performance, data that is already being collected on dairy farms was used.

The Whole Farm Model (Beukes et al., 2008) was used to identify the relationships that occur between pasture grown and data that is automatically collected in a growing number of dairies. The Whole Farm Model enabled a variety of scenarios to be explored in a short period of time and was ideal for this exploration work.

Materials and Methods

The Whole Farm Model was used to simulate a 3.0ha farmlet of 20 paddocks and 9 cows. The farm was run under normal farm practices to simulate what would typically take place on a commercially run dairy farm. The model was adjusted over a series of ‘runs’ to include more realism on each run.

Paddocks of variable growth abilities were created to simulate varying paddock performance with vast differences between the top and bottom performing paddock in terms of herbage accumulation (kg DM ha^{-1}) (Clark et al., 2010). Further to this, the model incorporated factors that mirrored common practice on dairy farms. Two of these factors were that; the ‘farmer’ had a 15% error rate when choosing the paddock with the most grass to graze the cows in. The paddock with the highest pasture cover was always grazed next, however the estimate of the paddock’s pasture cover had a random 15% error from the true value, therefore rearranging the correct order of paddocks to be grazed. Secondly, the cows grazed to a residual that match their feed demand rather than a set figure.

Settings – The farm was initially run over 365 days (1 June 2001 – 31 May 2002), closely following the decision rules outlined in Macdonald and Penno (1998). *See appendix for a full list of default settings used.*

The second run of the model had the time period increased to two full seasons (730 days) and all other settings remained consistent. The 2001/02 and 2002/03 seasons were chosen because of their similarity in rainfall distribution. Summer rainfall has a significant impact on summer herbage accumulation (Glassey, 2011) and by using seasons with similar rainfall distribution, there should be less influence from the climate on the results between the two seasons, therefore allowing a better comparison to be made. *See appendix for a full list of settings used.*

The third run included paddocks of varying sizes rather than all the same size. It also included a 15% error rate in herbage mass estimation which affected the ranking of paddocks and therefore the order of which they are to be grazed. A 15% human error rate meant, 95% of the perceived herbage mass covers will be within 70% and 130% of the true cover. Herbage mass estimation always contains a level of error. Common R^2 vales for herbage estimation when being calibrated to pasture are around 0.80 (L'Huillier and Thomson, 1988, O'Donovan et al., 2002a, O'Donovan et al., 2002b). *See appendix for a full list of settings used.*

The final run included a feature of the model (Conpast) that had cows eat to demand, rather than target post grazing heights. If cows were underfed for a day they would eat below the desired post grazing level and if cows were over fed they would leave more in the paddock than desired. This also had a follow on effect on herbage accumulation rates, whereby pastures not grazed hard enough would return to pre grazing herbage mass faster than paddocks grazed to target. The final run featured as much reality as possible to best demonstrate what we could expect on an actual farm. *See appendix for a full list of settings used*.

Analysis - Each paddock had herbage accumulation calculated for each season. Milk produced at each milking was attributed to paddocks grazed. The milk was attributed to paddocks that were grazed between 12 and 24 hours before the milking. The number of cows that grazed each paddock each day was counted and multiplied by the number of hours spent in that paddock. The total number of cow grazing hours per ha per year were counted and used as a predictor of herbage accumulation. Likewise, milk produced was counted per ha per year and used as a predictor for herbage accumulation.

Paddocks cut for silage were converted into expected milk produced values and expected cow grazing numbers. Expected figures were reached by working off the milk production and the number of cows in the herd for paddocks that were grazed with similar pasture covers at the time of the silage being made. These then gave an adjusted figure of cow grazing hours and milk produced.

Analysis of the whole farm model results were carried out using Microsoft Excel and the regression analysis feature.

Results

Results are set out for each model run.

Model run 1 – Running the model under default settings resulted in the paddocks growing between 10t DM ha^{-1} and 25t DM ha^{-1}. Adjusted milk yield production ranged from 15,000L ha^{-1} to 35,000L ha^{-1}. Using adjusted milk produced by each paddock for the year to predict the herbage accumulation was correlated with r = 0.72 (Figure 10). Adjusted cow grazing hours per ha, ranging from 15,000 to 30,000, were strongly correlated with herbage accumulation (r = 0.83) (Figure 10).

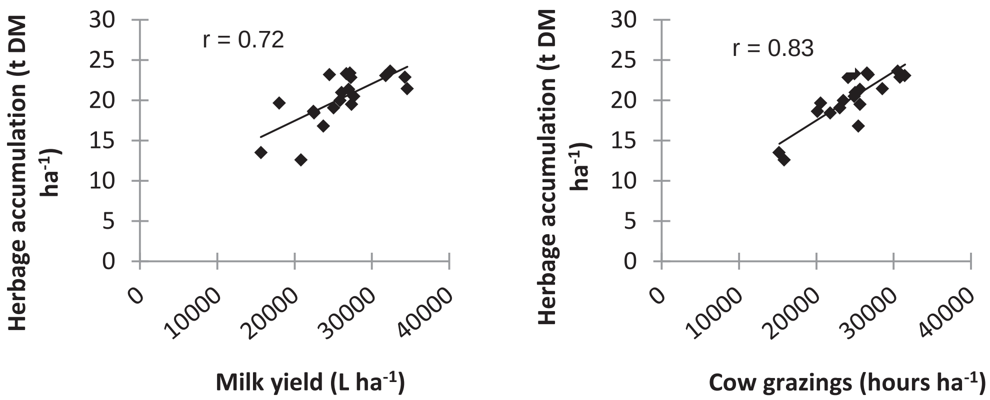

Figure 10: Run 1 - Calculated milk produced and cow grazing hours plotted against herbage accumulation from season 2001/02.

Model run 2 – Combining two consecutive seasons of data improved both relationships when an average figure was used. Under default settings over two consecutive seasons (2001/02, 2002/03) resulted in the paddocks growing between 10t DM ha^{-1} year^{-1} and 25t DM ha^{-1} year^{-1}. Adjusted milk yield production ranged from 15,000L ha^{-1} year^{-1} to 35,000L ha year^{-1}. Using the adjusted figures of milk produced by each paddock per year to predict the herbage accumulation was correlated with r = 0.82 (Figure 11). Adjusted cow grazing hours ranged from 15,000 to 35,000 ha^{-1} year^{-1}. Using the adjusted cow grazing hours ha^{-1} year^{-1} figure that each paddock endured to predict the herbage accumulation, was correlated with r = 0.94 (Figure 11).

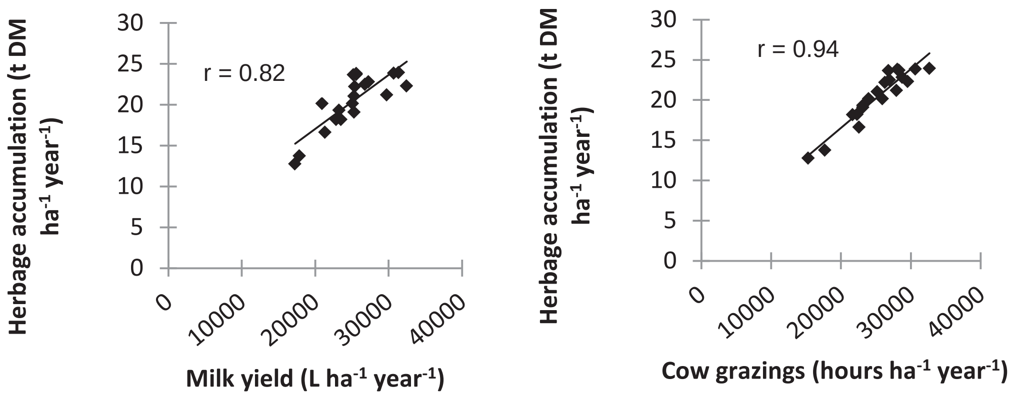

Figure 11: Run 2 - Calculated annual average milk produced and average cow grazing hours, plotted against average herbage accumulation from seasons 2001/02 and 2002/03.

Model run 3 – Paddocks were changed from one size to variable sizes in order to be comparable to dairy farms around New Zealand. In addition, an error was introduced when the paddock with the most pasture was chosen to be grazed next. Run 3 settings resulted in the paddocks growing between 15t DM ha^{-1} $year^{-1}$ and 25t DM ha^{-1} $year^{-1}$. The use of milk produced by each paddock for the year to predict the herbage accumulation was correlated with r = 0.78 (Figure 12). Adjusted cow grazing hours per ha per year was strongly correlated with the herbage accumulation (r = 0.90) (Figure 12).

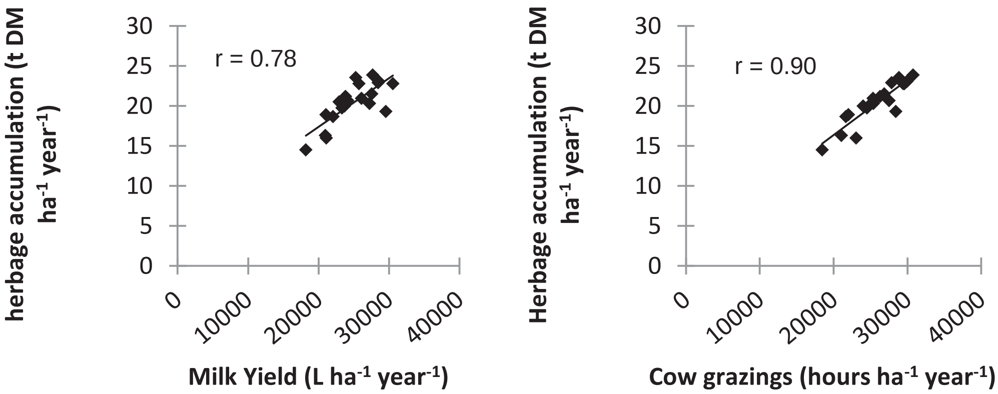

Figure 12: Run 3 - Calculated annual average milk produced and average cow grazing hours, plotted against average herbage accumulation from seasons 2001/02 and 2002/03.

Model run 4 – Rather than cows eating to target residual herbage masses, the cows in the model grazed to their demand. This change resulted in the paddocks growing between 15t DM ha^{-1} $year^{-1}$ and 25t DM ha^{-1} $year^{-1}$. Adjusted milk production ranged from 15,000L ha^{-1} $year^{-1}$ to

35,000L ha^{-1} year^{-1}. When milk produced by each paddock for the year was used to predict the herbage accumulation, the correlation was r = 0.82 (Figure 13). Adjusted cow grazing hours ranged from 20,000 to 30,000 ha^{-1} year^{-1}. When the adjusted cow grazing hours ha^{-1} year^{-1} each paddock endured was used to predict the herbage accumulation, the correlation was r = 0.92 (Figure 13).

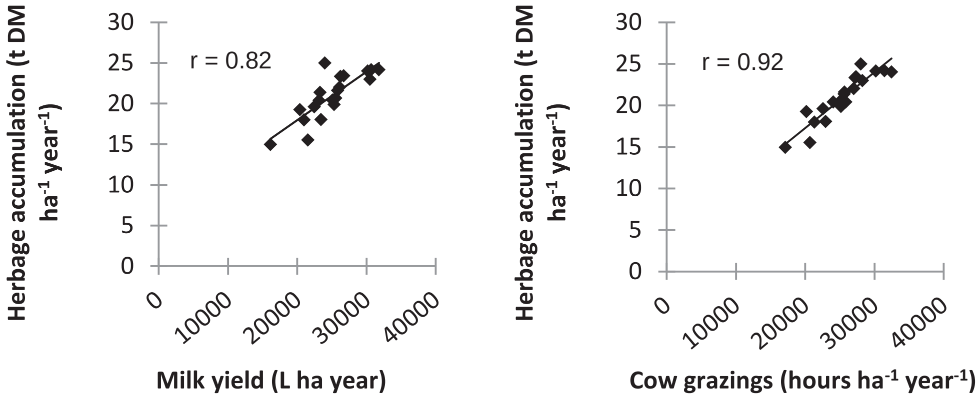

Figure 13: Run 4 – Calculated average annual milk produced and cow grazing hours, plotted against average herbage accumulation from seasons 2001/02 and 2002/03.

Model run 4: 365 days – To quantify the effect of season, the results from Model run 4 were separated into the two individual seasons. The season 2001/02 was more variable compared to results from season 2002/03. The correlation between cow grazing hours ha^{-1} and herbage accumulation for 2001/02 was r = 0.69 (Figure 14) while the correlation for 2002/03 was r = 0.91 (Figure 15). Similarly, the correlation between milk yield (L ha^{-1}) and herbage accumulation was less for the 20001/02 season (r = 0.56) than the 2002/03 season (r = 0.76).

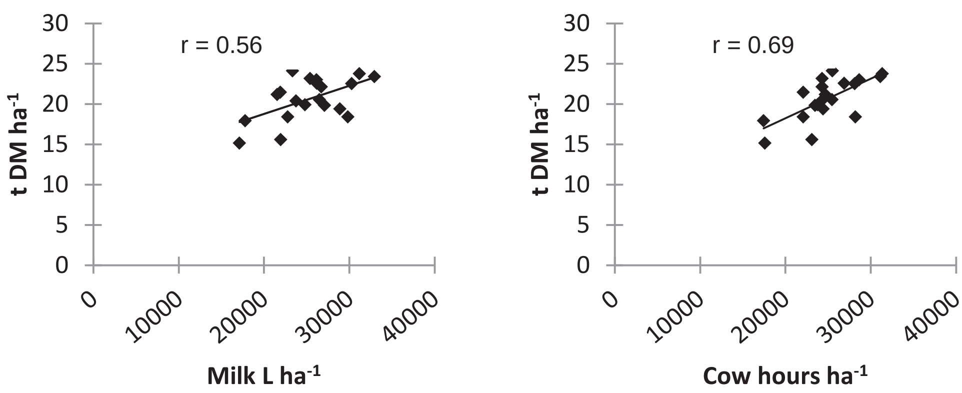

Figure 14: Calculated milk produced and cow grazing hours plotted against herbage accumulation for season 2001/02 from Model run 4 settings.

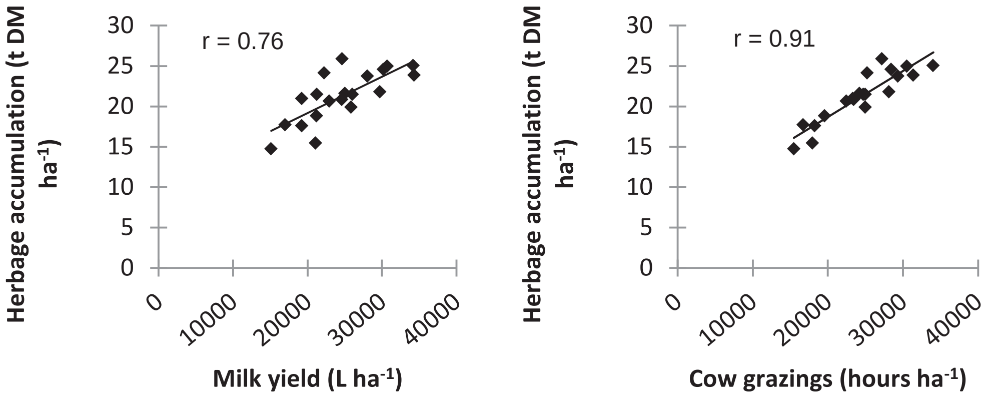

Figure 15: Calculated milk produced and cow grazing hours plotted against herbage accumulation for season 2002/03 from Model run 4 settings.

Discussion

The Whole Farm Model was used to simulate a small scale farm run under normal New Zealand conditions and management. The number of cow grazing hours each paddock endured and the amount of milk each paddock produced has been calculated and compared to the industry standard performance value herbage accumulation.

Results from the Whole Farm Model suggest it is possible to use the number of cow grazing hours each paddock endures to rank individual paddock performance and, to a lesser extent, milk produced by each paddock may be able to rank individual paddock performance. Correlations between cow grazing hours and herbage accumulation ranged from r = 0.69 for the season 2001/02 to r = 0.91 for the season 2002/03. Combining these results marginally improved the correlation to r = 0.92. Similarly, correlations between milk produced by each paddock and herbage accumulation ranged from r = 0.56 for the season 2001/02 to r = 0.76 for the season 2002/03. Combining these results improved the correlation to r = 0.82. This suggests data across a longer period results in a greater correlation, compared to smaller data sets that span one season.

Improved correlations when data is used across two seasons could be caused by a variety of factors. Management and decision rules for the farm were the same for both seasons, with the only differences being the climate years and the feed inventory of farm on June 1st. One possible reason the relationship improves when beyond one season is used, is that more paddocks on the farm are subjected to dry cow grazings. A paddock grazed by dry cows is disadvantaged by the amount of milk produced and the number of cow grazings that occur. Paddocks that are grazed by dry cows through the winter pick up extra grazing hours, however by being grazed through the winter they miss out on a rotation of grazing during early lactation. Paddocks not grazed during the winter are immediately available to be grazed by milking cows. Residuals left by milking cows (1500 kg DM ha^{-1}) allow a shorter return time compared to paddocks grazed by the dry cows (usually grazed to 1200 kg DM ha^{-1}). If two paddocks were grazed at the same time (one by milkers and one by dry cows), the paddock grazed by milking cows will be grazed again by milking cows before the paddock grazed by dry cows will be grazed by milking cows for the first time. Over one season, very few paddocks are grazed while the cows are dry. Over two seasons the number of paddocks grazed by dry cows has potentially doubled, therefore creating more of a blanket treatment to the farm and reducing the number of paddocks with an unfair advantage.

There are contrasting results between the two seasons analysed. The correlations for the season 2001/02 were poor in comparison to the season 2002/03. The reason for this is difficult to determine. The only major difference between the two seasons was the climate, however the two years were selected based on their similarities and should have not had a major impact on the results. Pasture growth remained similar between seasons as expected with similar rainfall distributions. The only other difference was the feed inventory of the farm at June 1st, however the difference was not to the extent that large differences in the correlations would be expected.

A variety of paddock sizes were incorporated into the model. Variable paddock sizes are common on dairy farms and demand a high standard of pasture management. As a result, paddocks are unable to be treated evenly and it can be difficult to estimate how much pasture is truly available. To simulate this, a 15% error rate in choosing the paddock with the most pasture was also introduced. The level of correlation with even sized paddocks over two seasons was $R^2 = 0.67$ for milk produced and $R^2 = 0.89$ for cow grazing hours. The introduction of variable paddock sizes and incorrect paddock selection had a negative impact on the relationships ($R^2 = 0.60$ and $R^2 = 0.81$ respectively). This result was expected as paddocks are no longer treated evenly and are grazed too early and too late, affecting pasture covers, milk production and the hours spent in the paddock. Over a season these factors compound to cause the negative impact.

Further consequences of cows grazing paddocks too early and too late was that feed demand was not met for the cows or there was an excess. When cows grazed to demand rather than set residuals it was expected to reduce the correlation between milk produced and pasture grown further, likewise the relationship between cow grazing hours and herbage accumulation. In spite of this, the correlation improved, providing a surprising outcome. The changes outlined caused paddocks to be over grazed when grazed too early and under grazed when grazed too late for some periods of the year. Consequently, the following grazing rotation was affected, with over grazed paddocks taking longer to reach pre-grazing targets and under grazed paddocks taking a shorter period to reach pre-grazing mass and daily milk production more variable with daily intakes varying. Clearly then there is a lack of evidence as to the underlying cause of the improved relationship with all evidence suggesting a further negative impact was to be expected.

Conclusion

Computer modelling has indicated that annual paddock performance can be determined by using grazing event data and to a less accurate level using milk production data. These types of data are more likely to be routinely collected on dairy farms as technology develops. This paves a future where farmers will potentially be able to obtain a performance ranking of each paddock that correlates to pasture production, allowing for farmers to make more informed strategic decisions surrounding their pasture and paddocks, therefore leading to a higher average pasture grown.

Chapter 5: Ranking paddock performance using data automatically collected by a dairy farm's milking system

Introduction

A significant proportion of dairy farms across New Zealand have large differences between the paddock that grows the most amount of grass, and the paddock that grows the least (Clark et al., 2010), therefore there is an opportunity to increase pasture production, which consequently increases milk production (Macdonald et al., 2001). Regular pasture measurements are required for farmers to identify which paddock is growing the least amount of grass which will assist in the decision making surrounding opportunities for either pasture renewal or further investigation into its poor performance. Yet historically pastures are not regularly measured by most farmers, mainly due to the physical and time consuming nature of the task. Many farmers use subjective measures to determine poor performing paddocks and may therefore not regrass the poorest performing paddocks. Consequently this reduces the profitability of the regrassing scheme because the maximum potential increase in average pasture growth has not been reached. The financial incentive is large if pasture growth is increased. For example an Upper North Island farm can potentially increase operating profit by \$354 ha^{-1} if an extra 1t DM ha^{-1} can be grown per year (Chapman et al., 2012, DairyNZ, 2013).

An easier method of ranking paddock performance may mean that farmers are more likely to use this information in their strategic decision making. In an attempt to create an easier method for ranking paddock performance, data that are already being collected on dairy farms was used. In this chapter, data was collected from a commercial farm to test the hypothesis that annual paddock performance can be determined by using milk production and grazing event data. The goal was to gain sufficient information to rank paddocks so the high performing and underperforming paddocks can be identified, rather than precisely measure the actual herbage accumulation. Previous work in Chapter 4 using the Whole Farm Model indicated this would be possible.

Materials and methods

Farm overview – The trial was conducted from December 2011 to December 2012 on a 200 ha, 600 cow dairy farm located in Pirongia, Waikato. The farm comprised four main blocks identified as N, E, S, and W. The farm dairy was located in N block (Figure 16) in the centre on the farm. The distance to the furthermost paddock on each block from the dairy was; N - 0.7km, E - 2.1km, S - 2.3km, W - 1.7km. The total mapped farm area was 205ha (includes gullies and swamps) (Figure 16) with the smallest paddock measuring 0.5 ha and the largest 4.4ha. Average paddock size was 1.4ha. The study started in summer and consequently there were two partial cycles of cropping and regrassing that took place through the study period. As a result, there was 25% of the farm already in maize or chicory when the trial started. At the end of the study 21% of the farm was being cultivated for the next summer's crops. Paddock cultivars were recorded for paddocks that these were known, for modelling purposes.

The cows were managed in two herds (herd 1 peaked at 290 cows; herd 2 peaked at 290 cows). A third group contained cows that required special treatment (mastitis or lame cows or colostrum cows) and were grazed in paddocks (N01, 02, 03, 04, 17, 18, 23, 24) that were close to the dairy. However when this herd was large (>30 cows) during calving, they grazed paddocks on the main milking platform.

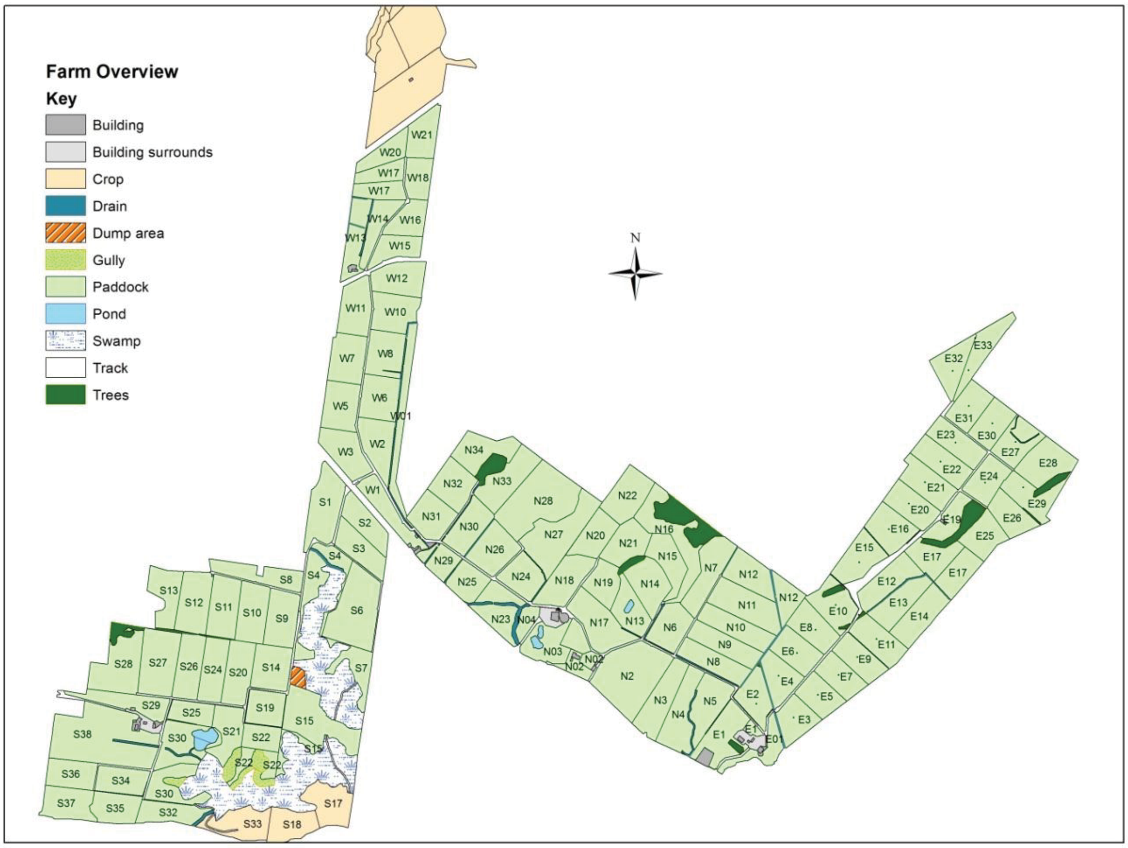

Figure 16: Farm overview. Paddock numbers and farm key.

Herbage accumulation – The herbage mass of each paddock was estimated weekly using a rising plate meter (RPM). The average ‘clicks’ (compressed half cm) were recorded for each paddock and fitted to the equation (herbage mass = RPM clicks x 140 + 500) to produce kg DM ha^{-1}. Annual net herbage accumulation for each paddock was calculated by summing the difference between the herbage mass after a grazing (post-grazing) and the herbage mass before the next grazing (pre-grazing) for each paddock. In the event a paddock was being grazed during the measurement, this was noted and the measurement excluded. If the fixed walking path within a paddock did not cross a mix of recently grazed and ungrazed pasture, this herbage mass was used as either the pre-grazing or post-grazing figure for the weekly calculation. Paddocks were not left half grazed beyond a couple of days. If the transect crossed both grazed and ungrazed pasture, the measurement was excluded.

Paddock location – Paddock grazing records were obtained using three GPS collars fitted to three cows in each herd. Three GPS units were satisfactory in order to identify each paddock grazed in the results from Chapter 3. Each GPS device was programmed to record one position for each paddock the cows grazed. During the AM milking the data was wirelessly and automatically downloaded. Coordinates were mapped onto a farm map and assessed to determine which paddocks were grazed, as described earlier (Chapter 3).

Milking data – The farm dairy was equipped with; electronic milk meters, automatic cluster removers, automatic walk over weigh scales, individualised in shed feed allocation, herd management software that recorded individual milking events and each cow was fitted with an electronic identification (EID) tag. The data used in the analysis were; cow number, AM and PM milk yields, days in milk, AM and PM live weights, herd number, time of EID, time of cluster attachment, time of exit and feed offered (kg) by each of four silos.

Calculations – Using Microsoft Excel, each milking report (AM and PM) was cleaned to remove cows that were recorded as being milked twice and calculations put in place to count the true number of cows being milked because cows were also missed as being milked.

A cow's second ID was removed if she was recorded twice, or more, in the one milking. The number of cows in each herd at each milking was then calculated rather than using raw output from the milking system. On rare occasions one or two cows would not be electronically identified, therefore reducing the number of registered cows for the herd. Consequently, the average number of cows recorded at three milkings was used as more often than not, all cows were recorded, meaning the average was the true number of cows. The milkings used were the previous milking, current milking and the next milking in time.

While cows were calving and being dried off, actual recorded cow numbers in the herd were used each day because there was a daily change in the number of cows. Small periods of missed data were assumed to be an average of data either side of the missing data.

Cow grazing events were counted by using the cleaned and averaged milking reports and GPS data. If two paddocks were grazed concurrently, the number of cows in the herd was split evenly and attributed to both paddocks regardless of their size.

Calculation of total milk yield (kg) for each herd was undertaken by multiplying the average number of cows (described above) and the average milk yield per cow (kg) as recorded by the milk meters. Before the average yield (kg) per cow was calculated for each milking, anomalous data were removed, i.e. all data from cows with a recorded milk weight either below 1kg or above 30kg, unless in herd 3. Average milk per cow was calculated using the remaining cows and this resulted in milk yields more representative of the actual milk yield, than using the raw numbers.

Fonterra milk composition records (milk fat %, milk protein %) and assumptions from Nicol and Brookes (2007) were used to convert 1 kg milk (recorded by the milk meters) to milksolids (MS) and calculate the MJ ME required by the cow to support that milk production. Milk produced in the AM milking was assigned to both the paddock grazed during the previous day and the paddock grazed before the AM milking. The milk yield from the AM milking was divided evenly and attributed to each of the two paddocks. Milk produced at the PM milking was assigned to paddocks using the same method. Literature surrounding the time it takes for grazed pasture to be harvested as milk suggests the time frame is somewhere between 9 and 24 hours (Bartsch et al., 1981, Sheahan et al., 2013). When two paddocks were grazed at the same time by the one herd, the milk yield was spilt evenly between the two paddocks regardless of their size.

To calculate pasture eaten, AM and PM cow energy requirements (MJ ME) were initially calculated using milk production records, stage of pregnancy, live weight and walking distance, using the assumptions described in Nicol and Brookes (2007). Then all supplement eaten as a figure of MJ ME was calculated by adding what was fed in the dairy and what was fed in the paddock. Estimates of wastage were removed from the total figure, leaving a figure of MJ ME supplements eaten. Finally, the energy supplied by the supplement eaten was subtracted from the total energy requirement and a figure of energy that was supplied by pasture remained. Energy required was converted to pasture eaten (kg DM ha^{-1}) based on the estimation that pasture quality was 11MJ ME $kgDM^{-1}$, which is arguably considered an average year round figure for Waikato pastures (Brazendale et al., 2011, Glassey et al., 2010). Quality measurements were not carried out and therefore a single quality figure was considered rational.

The equations used are expressed as:

*Total MJ ME required = (maintenance + pregnancy + races + milk production) * Number of cows*

Total MJ ME eaten as supplement = MJ ME fed in paddock + MJ ME fed in dairy - MJ ME fed but not eaten

Kg DM ha^{-1} *eaten by grass = (total MJ ME required - MJ ME eaten as supplement) / paddock size / 11MJ ME*

Cow activity energy requirements (MJ ME) were calculated using the following equation (Nicol and Brookes, 2007):

MJ ME races = LWT[(0.0026*H km)+(0.028*V km)]/Km*

where,
LWT = live weight
H km = horizontal distance travelled from dairy to paddock and back along race way,
V km = vertical distance travelled from dairy to paddock and back along race way,
Km = M/D*0.02+0.5
M/D = ME concentration of the feed DM (MJ ME $kgDM^{-1}$)
<u>Note:</u> Cow activity in the paddock was not included.

Whilst chicory fed was in a paddock, it was treated as supplement fed rather than another paddock being grazed. It was assumed that the cows were being fed 4kg DM cow^{-1} day^{-1} as per the farmer's targets. Another research project that was run simultaneously investigated the effectiveness of the RPM and capacitance probe at estimating the herbage mass of chicory. Yield measurements from this project confirmed 4kg DM cow^{-1} day^{-1} was being offered.

Live weight change is important for estimating cow energy requirements however this was not feasible in this research due to the variability in the data from each milking. Exclusion of these data resulted in a less accurate daily MJ ME requirement, however there was still sufficient confidence to continue using the static average cow live weight.

Analysis

Only paddocks that had ryegrass for the full 12 months during data collection were used. Paddocks that herd 3 grazed regularly were removed from the analysis, along with paddocks that were not suitable to be measured with the RPM. The analysis used 77 paddocks (106ha) out of a possible 125 (177ha). Paddock performance measures were; milk yield (kg MS ha^{-1}), cow grazings (events ha^{-1}), estimated pasture eaten (t DM ha^{-1}) and these were compared to herbage accumulation (t DM ha^{-1}). Two different approaches to analysis were undertaken. Firstly, the correlation coefficient (r) for each performance measure and herbage accumulation was calculated to indicate the strength of the relationship between the two variables being tested.

Secondly, paddocks were grouped into quartiles (Q1 = 0-25%; Q2 = 25-50%; Q3 = 50-75%; Q4 75-100%) to identify groups of poor performing paddocks rather than individual paddocks. The number of paddocks that were in each group was presented in a 2-way contingency table. Dependence of row and column variables was tested using the Chi-squared statistic and significance was determined at $P < 0.05$.

Results

Herbage accumulation on the farm ranged from 7t DM ha^{-1} (paddock W8) to 16t DM ha^{-1} (paddock N25), which is a difference of 130%. The average herbage accumulation was 10.5t DM ha^{-1}.

Grazing events vs herbage accumulation – Figure 17 displays the herbage accumulation on the left y axis and the cow grazing events on the right y axis for each paddock. Grazings ranged from 1,789 grazings ha^{-1} (paddock S30) to 3,672 events ha^{-1} (paddock W12), a difference of 105%. Overall there was no association between cow grazing events ha^{-1} and herbage accumulation. Figure 18 indicates when grazing events were used to predict herbage accumulation the correlation was weak $r = 0.24$. A strong relationship is indicated by $r > 0.70$.

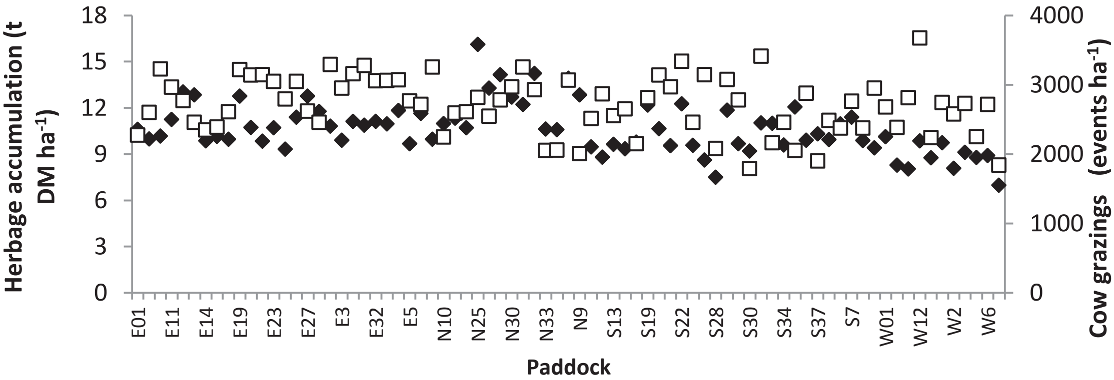

Figure 17: Herbage accumulation (t DM ha^{-1}) vs cow grazings (events ha^{-1}). t DM ha^{-1} (♦) cow grazing events ha^{-1} (□).

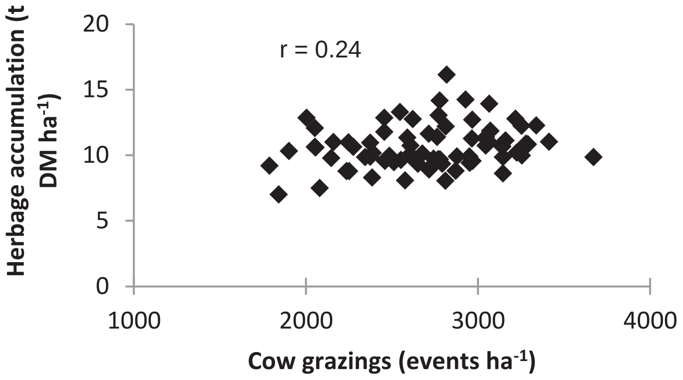

Figure 18: Cow grazings (events ha^{-1}) used to predict herbage accumulation (t DM ha^{-1}).

Paddocks were grouped into quarters for each performance measure. Q1 represents the lowest ranked 25% of paddocks. Numbers in each group are represented in a 2-way contingency table (Table 9) and tested using the Chi-squared statistic. For a perfect correlation, all paddocks in each quartile would align between the two performance measures and follow the dark green shade. The ranking of paddocks once fitted into quartiles based on cow grazing events and herbage accumulation were independent of each other (P>0.05). Table 9 displays that paddocks ranked in Q2 on cow grazing events ha^{-1} had many paddocks ranked in all four quartiles based on herbage accumulation, indicating disagreement between the two measures.

Table 9: Good (Q4), above average (Q2), below average (Q3) and poor (Q1) paddocks ranked according to cow grazing events and herbage accumulation.

Herbage accumulation (t DM ha^{-1}) quartile rank		Cow grazings (events ha^{-1}) quartile rank Q1	Q2	Q3	Q4	All
	Q1	6	7	5	1	19
	Q2	6	6	4	4	20
	Q3	5	2	4	8	19
	Q4	2	5	6	6	19
	All	19	20	19	19	77
						P-Value = 0.253

The two middle quartiles were merged to form a ranking of good, average and poor paddocks (Table 10). This further reduced the independence of paddocks and focused more on grouping paddocks to fit a bulk ranking system. The ranking of paddocks from both variables remained independent, with $P > 0.05$.

Table 10: Good (Q4), average (Q2 &3) and poor (Q1) paddocks ranked according to cow grazing events and herbage accumulation.

Herbage accumulation (t DM ha^{-1}) quartile rank		Cow grazings (events ha^{-1}) quartile rank Q1	Q2&3	Q4	All
	Q1	6	12	1	19
	Q2&3	11	16	12	39
	Q4	2	11	6	19
	All	19	39	19	77
					P-Value = 0.114

Milk yield vs herbage accumulation – Figure 19 displays the herbage accumulation on the left y axis and the milk yield per ha on the right y axis for each paddock. Milk yield ranged from 893kg MS ha^{-1} (paddock S34) to 2,079kg MS ha^{-1} (paddock S38), a difference of 121%. The milk produced by each paddock did not appear associated with herbage accumulation. Milk solid production was often high on paddocks that had low estimated pasture growth and paddocks that were estimated to have grown a lot of grass often produced lower amounts of MS. The correlation between kg MS ha^{-1} and herbage accumulation was low ($r = 0.28$) (Figure 20).

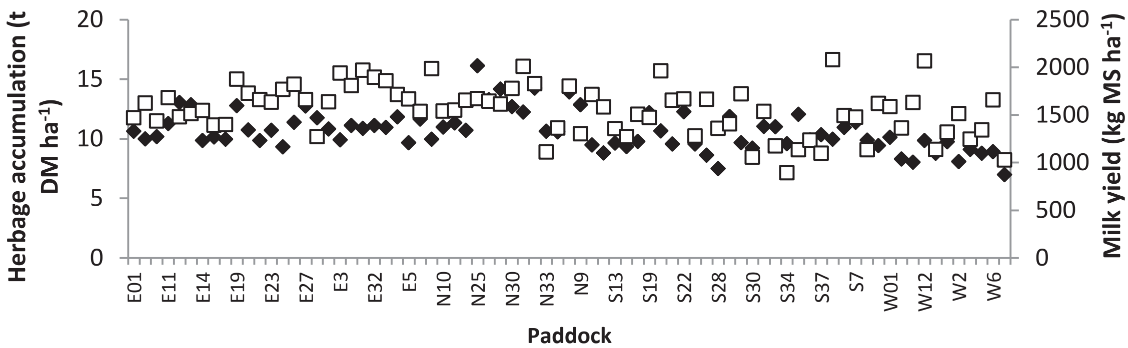

Figure 19: Herbage accumulation (t DM ha^{-1}) vs milk yield (kg MS ha^{-1}). t DM ha^{-1} grown (♦), kg MS ha^{-1} produced (□).

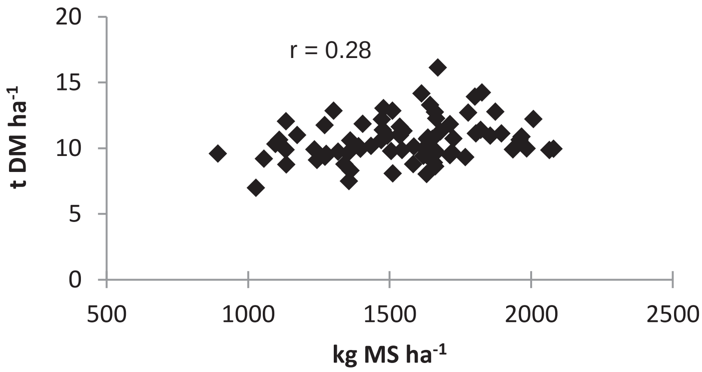

Figure 20: Scatter plot where milk yield (kg MS ha^{-1}) is used to predict herbage accumulation (t DM ha^{-1}).

The ranking of paddocks based on milk yield per ha and herbage accumulation were independent of each other (P>0.05). Table 11 displays paddocks ranked in Q1 by milk yield per ha produced, had many paddocks ranked in all four quartiles of pasture grown. In an ideal situation, all paddocks would be placed in the dark green boxes. There was no association between variables when the middle quartiles were merged to form good, average and poor groups of paddocks (P>0.05) (Table 12).

Table 11: Good (Q4), above average (Q2), below average (Q3) and poor (Q1) paddocks ranked according to cow grazing events and herbage accumulation.

		Milk yield (kg MS ha^{-1}) quartile rank				
		Q1	Q2	Q3	Q4	All
Herbage accumulation (t DM ha^{-1}) quartile rank	Q1	9	3	6	1	19
	Q2	5	6	4	5	20
	Q3	2	6	4	7	19
	Q4	3	6	5	5	19
	All	19	21	19	18	77
						P-Value = 0.200

Table 12: Good (Q4), average (Q2 &3) and poor (Q1) paddocks ranked according to cow grazing events and herbage accumulation.

		Milk Yield (kg MS ha^{-1}) quartile rank			
		Q1	Q2&3	Q4	All
Herbage accumulation (t DM ha^{-1}) quartile rank	Q1	9	9	1	19
	Q2&3	7	20	12	39
	Q4	3	11	5	19
	All	19	40	18	77
					P-Value = 0.058

Pasture eaten vs herbage accumulation – Pasture eaten ranged from 10t DM ha^{-1} (paddock N9) to 23t DM ha^{-1} (paddock E31) (Figure 21), a difference of 121%. There was a weak correlation (r = 0.22) between pasture eaten and herbage accumulation (Figure 22).

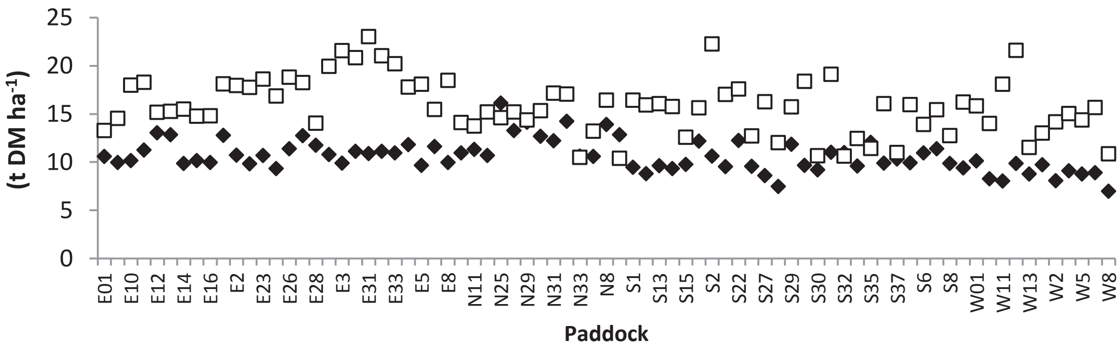

Figure 21: Herbage accumulation (t DM ha^{-1}) vs pasture eaten (t DM ha^{-1}). grown(♦), eaten (□).

Figure 22: Pasture eaten (t DM ha^{-1}) predicting herbage accumulation (t DM ha^{-1}).

There was a high degree of dependence between pasture eaten and herbage accumulation when graphed by quartiles (P=0.008) (Table 13) and when graphed as good, average and poor paddocks (P=0.002) (Table 14).

Table 13: Good (Q4), above average (Q2), below average (Q3) and poor (Q1) paddocks ranked according to cow grazing events and herbage accumulation.

		Pasture eaten (t DM ha^{-1}) quartile rank				
		Q1	Q2	Q3	Q4	All
Herbage accumulation (t DM ha^{-1}) quartile rank	Q1	7	4	7	1	19
	Q2	5	4	5	6	20
	Q3	5	3	1	10	19
	Q4	2	9	6	2	19
	All	19	20	19	19	77
						P-Value = 0.008

Table 14: Good (Q4), average (Q2 &3) and poor (Q1) paddocks ranked according to cow grazing events and herbage accumulation.

		Pasture eaten (t DM ha^{-1}) quartile rank			
		Q1	Q2&3	Q4	All
Herbage accumulation (t DM ha^{-1}) quartile rank	Q1	7	11	1	19
	Q2&3	10	13	16	39
	Q4	2	15	2	19
	All	19	39	19	77
					P-Value = 0.002

Predicting paddock performance – A partial least-squares regression was undertaken to identify if the pasture grown according to the RPM calculation could be predicted based on parameters relating to this specific farm. The key parameters were; the paddocks that were irrigated with effluent, the amount of supplement fed, if the paddock was a Base+Halo cultivar mix and if the paddock was in the W block of the farm. These four parameters were sufficient to predict a significant proportion of the variation in herbage accumulation, with a predictive R^2 of 53% or an R^2 of 58%. The key parameters that predict the herbage accumulation were identified after the removal of parameters that had little bearing on pasture growth (i.e. remaining blocks of the farm, other cultivars).

Grazing to milk conversion efficiency – Cow grazing events were compared to the kg MS ha^{-1} (Figure 23) for each paddock. As a result, this identified paddocks that were good and poor converters of grazings into milk yield. Figure 23 displays paddocks plotted by main herd cow grazing events (main milking herd) against main herd kg MS ha^{-1} produced. A line is fitted through the middle to indicate average conversion efficiency. Points above this line represent paddocks that are more efficient at converting grazings into milk yield and points below this line are paddocks that are less efficient at converting grazings into milk yield. Only milk and grazings from the main milking herd were used.

Small differences between paddocks are noticeable. Figure 23 indicates that paddocks in the S block produced less kg MS cow^{-1} grazing events than the other blocks of the farm. E block paddocks were the best converters of grazings into milk yield. Paddock S38 is arguably an outlier.

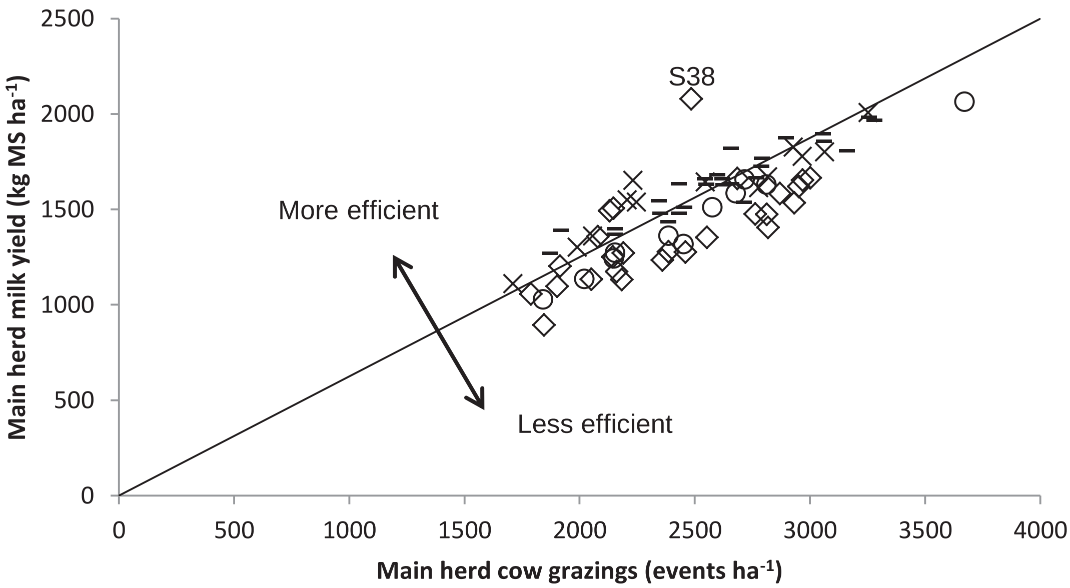

Figure 23: Scatter plot indicating the efficiency of converting grazings into milk. E block (-) N block (x), S block (◊) and W block (o).

Discussion

A trial was conducted on a commercial dairy farm in Waikato to test the hypothesis that data collected in a milking dairy by sensor technologies can be used to rank paddocks, based on a performance measure that correlates with the ranking gained by the industry standard herbage accumulation. Herbage accumulation was estimated by conducting weekly pasture assessments of every paddock on the farm with the RPM. Three new performance measures were created using the data from the milking system. These were cow grazing events ha^{-1}, kg MS ha^{-1} and t DM ha^{-1} pasture eaten. These methods of performance were tested against the herbage accumulation performance measure.

Paddock variability

Each performance measure (grazing events ha^{-1}; milk yield ha^{-1}; pasture eaten ha^{-1}; herbage accumulation ha^{-1}) recorded a difference greater than 100% between the best and worst performing paddock. A study by Clark et al. (2010) supports this result with common differences between the best and worst paddock being at least 50% but up to 122% in their study. The difference between the best and poorest performing paddock in this study were; herbage accumulation - 130%; grazing events - 105%; milk yield - 130% and pasture eaten - 121%. Although the range of performance is consistent across the measures, the order of which paddocks were ranked is not.

Identifying poor performing paddocks

There was an association between how much grass each paddock grew and how much was eaten by the cows. Although this association was weak, with 22 out of 77 paddocks being identified in matching quartiles by the two measures of performance (Table 13), pasture eaten ranking of paddocks was the closest match to the ranking of paddocks by estimated herbage accumulation. Primarily, paddocks that grow more grass should be grazed more often and produce more milk yield. Contrary to this, it was established there was no association between the grazing events ha^{-1} and milk yield with herbage accumulation. Furthermore, when paddocks were grouped into quartiles to reduce the variable nature of analysing on a paddock by paddock basis, there was also no association observed. The gazing performance measure was not consistent with Lincoln University Dairy Farm data (Lincoln University Dairy Farm, 2007, 2009) that had the ranking of paddocks by grazing events better matching herbage accumulation There is no relevant literature to compare attributing milk production to paddocks.

Conversion efficiency

The use of these data may be able to indicate conversion efficiency of pastures to milk. Paddock S38 was highly efficient at converting grazings into milk production. Reasons for this might be that it was influenced by management decisions because it was 1.6ha larger than the next largest paddock. Another consideration was that the paddock was a paddock that converted grazings to milk efficiently and days of consecutive grazing because of its size allowed a guarantee that milk was attributed to the correct paddock, while other paddocks never achieved this. Additional paddocks that had a high conversion of grazings to milk production may have had some of their milk attributed to other paddocks due to the uncertainty surrounding the time it takes for pasture eaten to be harvested as milk.

Modelling pasture growth

Ideally, partial least square regression modelling needs to be undertaken across numerous years and on multiple farms to be able to conclude that using information that is collected automatically in dairies can be used as a proxy for estimating pasture grown. This model presented is not able to be used on another farm as it has farm dependant variables, however it highlights that this type of modelling is possible and with a large robust data set, a model could be created and potentially integrated with pasture growth models that already exist (e.g. PGSUS).

Influencing Factors

Accuracy of estimated herbage accumulation - The accuracy of the estimated herbage accumulation needs to be surveyed. While initially these figures appear lower than average historical Waikato herbage accumulation data (Clark et al., 2010, Crush et al., 2006, Thom et al., 1993), more importantly, accurate estimates of herbage accumulation might not have been achieved and may answer why there was no association between milk yield and grazing events with herbage accumulation. Lile et al. (2001) reported that the RPM underestimates annual net herbage mass compared to visual scoring. Without an accurate measure of each paddock's standard performance, it is impossible to accurately match milk yield production and grazing events to herbage accumulation for each paddock. One factor that might cause variable results in herbage accumulation is the different measuring techniques between each person. Additionally, the transect across the paddocks is likely to be a leading cause of inaccurate estimates of what was truly grown per ha in each paddock, as we cannot be certain a fair representation of the paddock was reached. Dennis (2013) reported that within a paddock, herbage eaten as measured by the disappearance method can vary 100% and if the RPM transect is not crossing through a fair representation of the paddock, large discrepancies can occur between the paddocks true herbage accumulation and what the RPM estimates (Yule et al., 2010a).

Farm management decisions - Further contributing factors to the non-associations are believed to be from farm management decisions. Farm management decisions potentially dictate how much milk each paddock produces and how often they are grazed. Paddock sizes varied on the farm and often paddocks were treated under the same management practice regardless of size which therefore could have been a cause for milk production and grazing events not being associated with herbage accumulation. An example of how this happens can be appreciated when two paddocks side by side are due to be grazed with the same pasture cover per ha but are different sizes. One paddock is 1.2ha while the other is 1.5ha. The paddocks are treated the same, with the same number of cows grazing it and the same amount of supplement fed. Consequently the smaller paddock has less total pasture eaten and this may therefore be reflected in the milk production and exaggerated over a season. Because it is smaller, it has a higher number of grazing events per ha. Larger paddocks would have a similar effect, but the paddock is continually undergrazed and therefore the pasture quality declines, affecting milk production. Further supporting this was that paddocks that were irrigated with effluent on average had higher herbage accumulation than paddocks that did not receive effluent (Figure 25: appendix), yet there was no difference in the number of grazing events ha^{-1} Figure 26: appendix).

Further management decisions that can dictate the performance measure are secondary herds (dry cows, colostrum cows etc.). Paddocks that were grazed by dry cows may have had an unfair advantage under this performance measure because not all paddocks were grazed by dry cows. The dry cow herds through the winter contained upwards of 100 cows and generally spent three days in each paddock, attributing a further 300 grazings to each paddock that otherwise would not have been achieved had the dry cows not grazed the paddock.

Herd 3 were generally kept to their own paddocks off the main milking platform and close to the dairy. During the peak of calving however, this herd became large and they grazed paddocks that were part of the main milking platform. Paddocks; S1, S2 and S3 were the main paddocks used and Figure 24 (appendix) highlights the large contribution that herd 3 gave to those paddock's total milk yield. Had the milk from herd 3 been excluded, the performance measure for the paddocks herd 3 grazed would have been less than their true performance. This result emphasises the importance of using milk meters in this project, rather than 24 hourly bulk milk vat results from the milk company, Fonterra. Milk from herd 3 never enters the bulk milk vat and so therefore is not attributed to paddocks as there is no record of it. Furthermore, if the farm has more than one herd, it is impossible to differentiate the amount of milk produced by each herd.

Accuracy of supplementary feed measurement - Pasture eaten figures are notably high and the cause of this was partially isolated to the recorded supplement fed in the paddock by the farmer. Supplement fed in the paddock is difficult to record as there is no autonomous recording technology. There was likely an underestimation of amount of supplement that was fed in the paddock by the farmer and an over estimation on our behalf of how much of this was being wasted (not eaten). Increasing the amount of supplement eaten would decrease the amount of pasture eaten to more realistic figures. Never-the-less, the supplement fed figures were left as recorded because the supplement fed in the paddock was aimed to be the same amount each day and was not paddock dependant. Furthermore, an actual figure of pasture eaten was not the goal. The target was to gain a ranking of paddocks based on pasture eaten and this was achieved.

Another possibility for the large pasture eaten figures was that the estimated pasture quality figure of 11kg DM MJME^{-1} was incorrect. No pasture quality samples were taken and therefore an estimate was made at 11MJ ME. Underestimation of the true pasture quality would cause the total kg DM ha^{-1} eaten to be greater than actual. For example, increasing the quality from 11MJ ME to 11.5MJ ME would reduce the average pasture eaten by the cows to 15,100kg DM ha^{-1} from 15,800kg DM ha^{-1}. Alone, this possible cause for high pasture eaten estimates is not enough to solve the problem, however coupled with inaccuracies in supplement recording we may be able to largely explain how it has occurred.

Future work – Overall, it cannot be ruled out that the results obtained were possibly affected by this farm using a large amount of supplementary feed. Therefore this trial should be repeated on a unique pasture-only dairy farm to prove the concept, before being extended onto common New Zealand dairy farms with supplement use. This would enable the removal of the supplement fed variable that has been identified as a key influencer in these results. Using a system where pasture is the sole feed will give a more accurate representation of how each paddock is performing. Furthermore, using multiple methods of herbage accumulation assessment would be necessary along with season pasture quality assessments.

Summary - It was concluded in Chapter 4 that using the number of cows that graze a paddock over a season and how much milk each paddock produces would be strongly correlated to herbage accumulation. Results from this commercial farm suggest there are more factors that need considering than originally thought. Possible factors for why there was limited associations observed between the trail performance measures and the industry standard have been discussed, however there is no evidence to support these claims, and therefore further work is required to better understand the cause.

Conclusion

None of the three new performance measures (grazing events ha^{-1}; milk yield ha^{-1}; pasture eaten ha^{-1}) correlated well with the industry standard measure of estimated herbage accumulation. This was despite more than a 100% difference between the best and poorest performing paddock for each performance measure conducted in this trial.

Pasture eaten was the best estimate of herbage accumulation and until further research identifies more effective measures for managing the variation that likely caused poor correlations, it is not likely to be an effective sole means of ranking paddock performance.

Chapter 6: General Discussion

Introduction

A series of trials have been conducted to test the hypothesis that data collected in a growing number of dairies throughout New Zealand can be used to rank paddocks based on their productivity performance of herbage accumulation. Firstly computer modelling in the form of DairyNZ's Whole Farm Model was used to test the hypothesis. Conclusions from this process were supportive of replication on a commercial dairy farm. Data was then collected by information and sensor technologies in a commercial New Zealand dairy and tested to investigate whether these data can be used to accurately rank paddocks based on their annual performance. Paddock performance was acquired by three different measures; cow grazings (events ha^{-1}), milk yield (kg MS ha^{-1}) and pasture eaten (kg DM ha^{-1}). Each method took a different approach to how these data were used. These performance measures were assessed against the standard performance measure of a RPM to estimate herbage accumulation by each paddock. Prior to conducting this, a method of collecting paddock grazing event data was required. GPS was chosen as the most suitable option and subsequently GPS devices were tested under static conditions with the purpose of simulating the minimum requirements for obtaining accurate paddock grazing event data. This discussion details and concludes key aspects of the entire project described.

Paddock performance variation

Every performance measure obtained a large difference between the top and bottom performing paddock (>100%) which is consistent with Clark et al. (2010). However the order of which the paddocks were ranked was different and subsequently produced weak correlations between the measures. This was not consistent with the results from the Whole Farm Model work that concluded strong relationships between herbage accumulation and the new performance measure. The Whole Farm Model suggested a correlation of r = 0.92 when cow grazings (hours ha^{-1}) were ranked against herbage accumulation. The commercial farm trial gained r = 0.24 for ranking cow grazings (events ha^{-1}) against herbage accumulation. Similarly the Whole Farm Model indicated r = 0.82 was achievable between milk yield (L ha^{-1}) and herbage accumulation, however the commercial trial obtained r = 0.28 for milk yield (kg MS ha^{-1}) against herbage accumulation. Reasons for the different ordering of paddocks require critical analysis of each performance measure.

Herbage accumulation – The estimated herbage accumulation by the RPM is an estimate and not a true value and therefore the reliability needs to be considered. There is evidence to suggest variation and underestimation occurs when the RPM is used to measure net herbage accumulation as in this case (Lile et al., 2001). Furthermore variation occurs within paddocks which highlights how important it is to have a transect of the paddock that represents the average of the paddock (Dennis, 2013). This arguably raises the question, which method of measuring paddock performance is giving the best representation of every paddocks economic value to the farm?

Milk yield – Milk yield as a measure of performance may have been affected by the management of the farm and a relatively poor understanding of timing around feed eaten and milk synthesis. The farm was focused on per animal milksolids production and subsequently for much of the year the cows were fed large amounts of supplement feed, causing pasture to not be the main production driver. As a result, milk yields may not represent pasture grown because there were often large quantities of pasture left behind after grazing which indicates they were sufficiently fed by supplements.

In addition it is unclear the milk yield response cows have to changing daily dry matter intakes. Literature indicated a response time period to increased feed or restricted feed (Bartsch et al., 1981, Sheahan et al., 2013), however the size of the response is hard to interpret and integrate into this work.

Pasture eaten – Because milk production and supplementary feed were key variables used in calculating pasture eaten, it too was affected by the same problems as milk yield and resulted in more pasture being eaten than was grown. Pasture eaten was further affected by supplements fed. Supplements fed in the paddock were the only non-autonomous data recording in the project. Estimates of daily feed fed were used and after double checking every other variable, it was concluded more supplement was fed than estimated. Furthermore, the estimated wasted feed was likely less during periods of the year than the recommended values. This resulted in more supplement feed being eaten than estimated, therefore reducing the amount of pasture calculated to have been eaten.

Another possibility for the large pasture eaten figures was that the estimated pasture quality figure of 11kg DM $MJME^{-1}$ was incorrect. No pasture quality samples were taken and therefore an estimate was made at 11MJ ME. Underestimation of the true pasture quality would cause the total kg DM ha^{-1} eaten to be greater than actual.

Grazing events – Grazing events relied on sticking to strict decisions rules to obtain similar results that the model gained. However in reality strict decision rules are not always the best decision for other reasons. It was identified in Chapter 4 that the dry period was a key period for skewing results and collecting data over two seasons reduced the effect. The commercial trial suffered the same dry period problem and time did not allow a second season to be tested. Some paddocks were not grazed over the winter while others received dense dry cow grazings. In addition, paddocks of different sizes were treated the same and resulted in more or less grazing events per ha depending on its size.

Summary – It is essential that we gain better understanding of why there was no association between the trail performance measures and the current industry standard performance measure of herbage accumulation. A more informed understanding of what is occurring will allow a better judgement for assessing the best method of measuring paddock performance. Although currently these three measures do not match estimated herbage accumulation, they could be implemented on farms that do not have any form of herbage accumulation assessment to help build that educated assessment of the paddock's performances and lead to more informed strategic decision making.

GPS to record grazing events

The use of GPS to locate which paddock a herd of cows grazed each day was tested. Firstly, to determine the minimum number of GPS units and the fix rate required to accurately record the paddock being grazed by cows, a simulation was carried out to acquire default settings and the requirements from GPS units. Paddock size and shape affect how precisely GPS devices can locate the correct paddock. It was decided that a minimum of three GPS units per herd were required to sufficiently record paddocks that were grazed. These units need to have a tested accuracy of no more than six metres (95% CEP 6m, or +/- 6m) to accurately measure a paddock of 0.5ha and the number of location fixes required per paddock needs to be at least three.

It was initially expected changes in accuracy throughout the day would affect the probability of locating the correct paddock however this was not the case. The time of day that a location is taken has less than 1% effect on the probability of locating the correct paddock. Therefore the time that location fixes are taken can be at any time during the day or night, providing the cows are in the paddock.

Research in the field of using GPS tracking technology on dairy cows is limited, however as the price of these units decreases, the viable economic use of them will grow in research and farm system purposes. Potentially GPS devices will be on every cow in a herd and be used to measure where they are at regular intervals, enabling behaviour database of each cow to be built. Subsequently these data may be used to identify lameness, heat detection, calving and problematic calving, when they have run out of grass and alert for when cows are in places they are not supposed to be.

Future work

To appreciate why counting grazing events and attributing milk to paddocks grazed did not clearly identify the top and bottom performing paddocks in terms of herbage accumulation, a number of trials could be conducted to help eliminate potential causes and potentially identify weaknesses in the methodology.

A complete understanding is required of the lag time between when a cow eats pasture and when the response in milk yield is observed. One potential trial that may help build that knowledge is to have three groups of cows fed the same pasture allowance and one group change to an increased pasture allowance and another group to a decreased allowance throughout the trial. Observations could be made at the subsequent milking sessions to identify how long it took to see a reduced or increased milk yield. More groups may be added and the size of the change in feed allowance could be investigated to measure the size of the milk response.

A further trial could have cows on a randomised, variable pasture allowance. Milk yields could be measured to investigate how much ‘buffering’ occurs by the cows. Buffering occurs where the cow’s milk yield changes little on a daily basis even though their intake is variable. Gaining robust results here will help to isolate, expel or prove what effect the cows were having on this trial.

Further work repeating this trial on a low input farming system could remove the issues surrounding the recording of supplements. Additionally this farming system will have more emphasis on the pasture production as the driving force behind the cow’s milk production, unlike in high input systems where supplements make up a significant proportion of daily energy intakes. Paddocks in the low input system better represent their actual value to the farm. Recording soil types, soil moisture, soil fertility, local climate data, and using multiple methods of herbage accumulation assessment would further enhance the ability of replicating the modelling results. Multiple methods of herbage accumulation estimates are required to ensure a robust estimate of each paddocks standard performance is reached. Quarterly pasture samples will be required to appreciate the variable nature of pasture quality between seasons and between paddocks.

Repetition on a farm that uses supplements (approximately 4 – 20% of total feed being imported, Systems 2 and 3) will require precise measurement of daily feeding. Pre and post grazing pasture covers will be required for each paddock to calculate actual pasture eaten. Supplement fed in the paddock will need to be tested for quality and DM%, as well as scales on the feeding wagon, to calculate the quantity fed. An estimation of how much supplement was wasted in the paddock will be required on a paddock by paddock basis, daily. Furthermore supplement fed in the dairy must be monitored in the same manner it was throughout this trial, however observations need to be made when a change of feed occurs exiting the silo, rather than when it was delivered.

Additional work is required to build a software system that uses the data captured automatically by the GPS system and connects this to a digital map of the farm. A probable method of automatically taking the location figure and turning it into a paddock number will be the use of the mathematical equation ‘winding number’. This is something that needs to be investigated further, however the platform for the accuracy and settings of GPS devices needed to automatically record paddock allocation has been calculated and tested in the field.

Conclusion

The final concluding remarks for this thesis are:

- GPS can be used as a tool to automate the recording of paddock grazing events on New Zealand dairy farms.
- Modelling results exhibited strong relationships between grazings and pasture grown, while milk production and pasture grown was identified as being moderate, however this came with real world limitations.
- The use of in-shed technologies has enabled the ability to create new automated methods of assessing paddock performance.
- Surprisingly these methods do not match how much pasture the paddocks were estimated to have grown.
- The underlying causes of the result are thought to be; the estimated herbage accumulation figures, the estimated figures of supplements fed in the paddock and the level of wastage occurring, and finally the lack of knowledge for the interaction between changing daily feed intake and their milk production response time and size.
- Further work is required to gain a clearer understanding of why the performance measures do not match before they can be used as a proxy for herbage accumulation.

Appendix

Whole Farm Model settings

Default settings

- 365 days (1 June 2001 – 31 May 2002)
- Farm size 3.0ha
- 20 paddocks (all 0.15ha)
- 9 cows (3.0 cows ha^{-1})
- Calving – July 10th
- Animal model – Molly cow
- Pasture model – McCall
- Climate data from Ruakura
- Cows are fed to demand
- Milkers fed silage to meet demand between 1 Jan and 31 August
- Drys fed silage to meet demand
- Rotation length varies between 20 days in spring to 100 days in winter
- Residuals are to set between 800kg DM in winter and 2050kg DM in the summer
- Fertilizer throughout the year following the cows (40kg N ha^{-1})
- Shut up for silage when surplus detected between September and December
- Cut silage when shut up paddock is over 3000kg DM ha^{-1}
- Cows are dried off if 70 days out from milking or farm cover drops below 1800kg DM ha^{-1} or 150 days before calving if BCS under 2.5; 120 days out if under 3, 90 days out if under 3.5
- All young stock grazed off
- Starting cover average 2450kg DM ha^{-1}
- Each paddock grows at different rates

Run 2 settings and decision rules

- 730 days (1 June 2001 – 31 May 2003)
- Farm size 3.0ha
- 20 paddocks (all 0.15ha)
- 9 cows (3.0 cows ha^{-1})
- Calving – July 10th
- Animal model – Molly cow
- Pasture model – McCall
- Climate data from Ruakura
- Cows are fed to demand
- Milkers fed silage to meet demand between 1 Jan and 31 August
- Drys fed silage to meet demand
- Rotation length varies between 20 days in spring to 100 days in winter
- Residuals are to set between 800kg DM in Winter and 2050kg DM in the Summer
- Fertilizer throughout the year following the cows (40kg N ha^{-1})
- Shut up for silage when surplus detected between September and December
- Cut silage when shut up paddock is over 3000kg DM ha^{-1}
- Cows are dried off if 70 days out from milking or farm cover drops below 1800kg DM ha^{-1} or 150 days before calving if BCS under 2.5; 120 days out if under 3, 90 days out if under 3.5
- All young stock grazed off
- Starting cover average 2450kg DM ha^{-1}
- Each paddock grows at different rates

Run 3 settings and decision rules

- 730 days (1 June 2001 – 31 May 2003)
- Farm size 3.02ha
- 20 paddocks (0.1-0.2ha, average size 0.151ha)
- 9 cows (2.98 cows $^{-1}$ha)
- Calving – July 10th
- Animal model – Molly cow
- Pasture model – McCall
- Climate data from Ruakura
- Cows are fed to demand
- Milkers fed silage to meet demand between 1 Jan and 31 August
- Drys fed silage to meet demand
- Rotation length varies between 20 days in spring to 100 days in winter
- 15% error rate in herbage mass estimation
- Residuals are to set between 800kg DM in Winter and 2050kg DM in the Summer
- Fertilizer throughout the year following the cows (40kg N $^{-1}$ha)
- Shut up for silage when surplus detected between September and December
- Cut silage when shut up paddock is over 3000kg DM ha^{-1}
- Cows are dried off if 70 days out from milking or farm cover drops below 1800kg DM ha^{-1} or 150 days before calving if BCS under 2.5; 120 days out if under 3, 90 days out if under 3.5
- All young stock grazed off
- Starting cover average 2450kg DM ha^{-1}
- Each paddock grows at different rates

The final settings and decision rules

- 730 days (1 June 2001 – 31 May 2003)
- Farm size 3.02ha
- 20 paddocks (0.1-0.2ha, average size 0.151ha)
- 9 cows (2.98 cows ha^{-1})
- Calving – July 10th
- Animal model – Molly cow
- Pasture model – McCall
- Climate data from Ruakura
- Cows are fed to demand
- Milkers fed silage to meet demand between 1 Jan and 31 August
- Drys fed silage to meet demand
- Rotation length varies between 20 days in spring to 100 days in winter
- 15% error rate in herbage mass estimation
- Residuals are to the cows feed demand but based around target residuals (Conpast pasture model)
- Fertilizer throughout the year following the cows (40kg N ha^{-1})
- Shut up for silage when surplus detected between September and December
- Cut silage when shut up paddock is over 3000kg DM ha^{-1}
- Cows are dried off if 70 days out from milking or farm cover drops below 1800kg DM ha^{-1} or 150 days before calving if BCS under 2.5; 120 days out if under 3, 90 days out if under 3.5
- All young stock grazed off
- Starting cover average 2450kg DM ha^{-1}
- Each paddock grows at different rates

Extra graphs

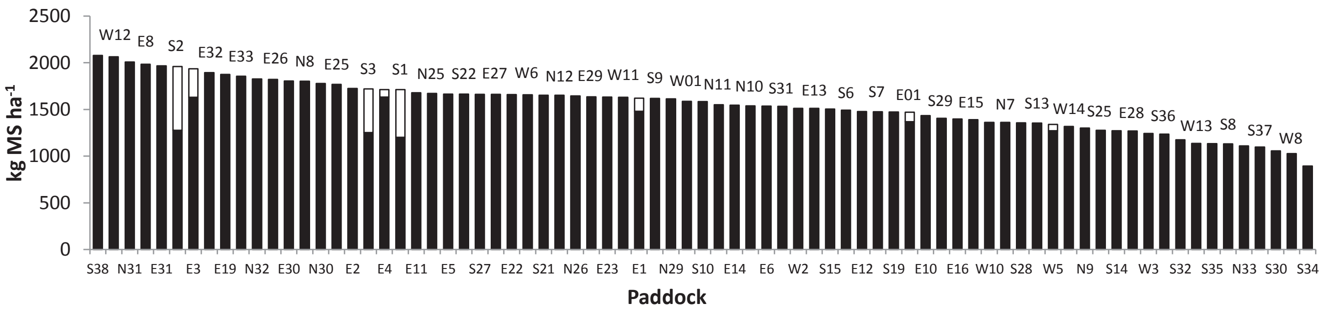

Figure 24: Milking cow and colostrum/sick cow kg MS ha^{-1} produced by each paddock. Main herd (█) and herd 3 (□).

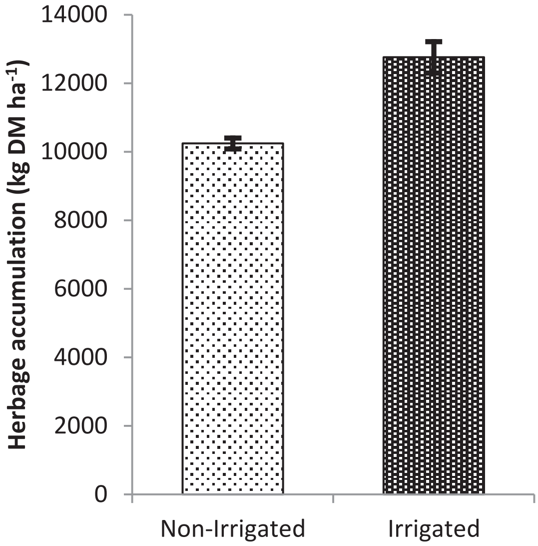

Figure 25: Average herbage accumulation for paddocks with or without effluent. Paddocks that had no effluent (░) and paddocks that received effluent (▓), 95% confidence interval (I).

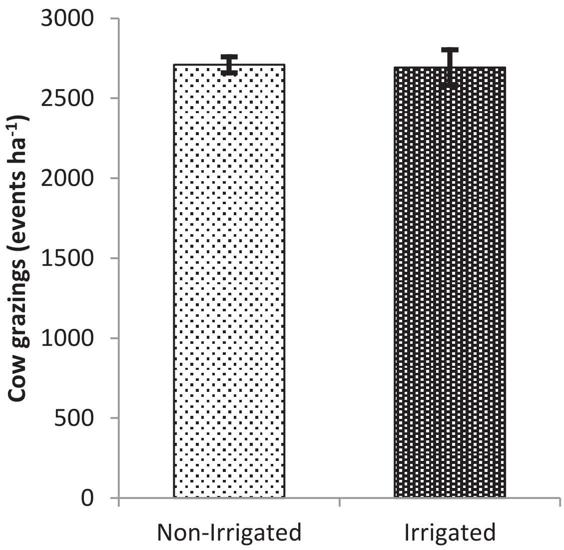

Figure 26: Average cow grazing events per ha for paddocks with or without effluent. Paddocks that did not receive effluent (░) and paddocks that received effluent (▓), 95% confidence interval (I).

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