Validating satellite monitoring of dairy pastures in Canterbury with Lincoln University Dairy Farm and commercial farm data

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Abstract
Validation of satellite-based prediction of pasture cover for dairy farms in Canterbury (New Zealand) during the 2008 and 2009 milking seasons is reported. Satellite-based predictions made using the new Canterbury model were validated against estimates from a rising plate meter for the Lincoln University Dairy Farm (LUDF) weekly farm walks and from nine commercial farms, across 15 images. Validation against LUDF data showed high coefficients of determination (mean R^2 = 0.85, range 0.69 to 0.97 kg DM/ha) and low residual standard errors (mean RSE =138 kg, range 53 to 244 kg DM/ha). Validation against commercial data showed a higher level of variability between farms and images than the LUDF data. The Canterbury model accounted for a large proportion of the observed variability in pasture cover of dairy pastures when matched to high quality data, and showed seasonal trends in the model coefficients. Higher variability associated with commercial data may be attributed to geographic distribution, timing and method of data collection as well as varying levels of competency in monitoring skills.
Keywords: Pasture, monitoring, satellite data, paddock ranking, pastures from space

Introduction
As part of the Pastures from Space® project in New Zealand (Clark *et al*. 2006; Dalley *et al*. 2009; Mata *et al*. 2007, 2010), a new model has been developed for the Canterbury Plains.

Developing a model for Canterbury, where the milking season extends from August to March, and contains both a "rain-fed" and an "irrigated" phase with the transition period generally occurring in late October, adds an extra level of complexity compared to the "rain-fed" Waikato system. The pasture composition and structure that develops in Canterbury during the irrigation phase differs to the Waikato pastures. In particular, the combination of regular high moisture and high temperatures leads to the rapid microbial breakdown of mature residual biomass, resulting in almost constant post-grazing pasture cover of approximately 1500 kg DM/ha. Without this accumulating litter, exposed soil would be expected to make a greater contribution to the remotely-sensed reflectance signal of recently grazed paddocks, potentially increasing between-farm variability due to soil types. Additionally, surface water from the irrigation process itself could affect the remote sensing of pastures in a non-uniform manner, depending on the method of irrigation used (Beget & Di Bella 2007).

Validation of predictions from the Waikato model (Mata *et al*. 2007, 2010) showed that for the "rain-fed" Waikato pasture production system, the model explained approximately 60% of the observed variability over two milking seasons (residual standard errors (RSE) of 270 and 360 kg DM/ha). However, within each season the Waikato model performed better in winter and early spring, but lost sensitivity towards early summer. While the number of paddocks with predicted mass within ±400 kg DM/ha of field observations in Waikato remained constant at approximately 75% for each milking season, across-season declines in the R^2 and ranking coefficients corresponded to decreases in the pasture cover range (PCR) to less than 1000 kg DM/ha for the period approaching "balance day" (pasture accumulation on farm exceeds pasture consumption) and the silage making period.

Validation of predictions from the Waikato model was based on ground data collected by the DairyNZ technical team, following well-defined protocols based on published guidelines (Lile *et al*. 2001; Thomson *et al*. 1997). While this method provided the best data quality possible, it may not necessarily have been representative of the dairy industry as a whole, where pasture monitoring activities take a lower priority during busy periods (Dalley *et al*. 2009) and the rigour required for accurate assessment may be lost.

The most commonly used monitoring practices in the industry are based on indirect measurements and include both objective (rising plate meter (RPM) and published equations (Thomson & Blackwell 1999)) and subjective (un-calibrated visual estimates) approaches.

In this paper we report on the validation of pasture cover predictions made from satellite-based images using the Canterbury model over two seasons and compare the performance of the satellite predictions against data from nine commercial and one research farm.

Methods

Study location

A total of nine commercial farms and the Lincoln University Dairy Farm (LUDF) were used in this study to collect ground validation data to match to satellite predictions of whole paddock pasture cover. Their geographical distribution in the Canterbury Plains, South Island, New Zealand is shown in Fig. 1, and the characteristics of each farm are listed in Table 1. In this paper "year" or "season" are considered to begin at the winter solstice (21 June), to capture the management cycle associated with seasonal, spring calving, dairy systems with an irrigation phase.

Satellite images

The acquisition of satellite images for monitoring dairy pastures in New Zealand has been described by Mata *et al.* (2007) and Clark *et al.* (2006). Processing of satellite images and the operational implementation of the models to predict pasture cover was carried out by Landgate (www.landgate.wa.gov.au). They used a Pastures from Space® workflow that captures a semi-automated data processing and delivery system for the implementation of the model and the delivery of data to producers and research collaborators. A separate publication is being prepared describing the development of the Canterbury Pasture Cover Prediction Model. Table 2 presents the schedule of image acquisitions, between August 2008 and March 2010.

Ground data collection and pre-processing

Data to validate the satellite-based model predictions were sourced from a) the LUDF weekly farm walks by selecting dates from the published walks (www.siddc.org.nz) that were closest to the dates of image acquisition and b) from participating producers collaborating in this research. The LUDF was established as a demonstration farm, and conducts weekly farm walks. These farm walks have become the industry bench-mark for regular and rigorous pasture monitoring, on which to base grazing management, feed budgeting and feed allocation decisions. The LUDF data were estimated using a RPM and converted to "kg DM/ha" using the DairyNZ winter equation (kg DM/ha = RPM × 150 + 500, (Thomson & Blackwell 1999). While the authors recommend using the monthly equations, producers have adopted using the winter equation throughout the year for simplicity (D. Dalley unpublished). There were 15 datasets with a total of 240 paddock values received from LUDF, and all data were within ±3 days from image acquisition.

Commercial pasture cover data used for validation were collected as either uncalibrated visual estimates or using a RPM, and were received as "kg DM/ha" with no indication of the method or conversion equation used. Participating farmers were asked to supply data from their regular activities and as close as possible to the date of the image acquisition, rather than to conduct specific farm walks to match satellite imagery dates. Therefore, the initial spread of days between farmer-collected data relative to image dates was greater than for the LUDF data (Fig. 2). Sources of error were identified prior to validation analysis.

Quality control of ground and satellite data before analysis

To minimise the impact of the number of days between field data and image acquisition, all field data were corrected to the date of the image acquisition using the published LUDF weekly whole-farm pasture growth rate (GR, (www.siddc.org.nz)) information. All data were assessed using three initial factors before inclusion

Table 1 Property ID for the nine commercial farms and LUDF, irrigation system and total number, minimum, maximum and average paddock size and the effective area.

Farm ID	Irrigation type	Num. pdk	Min pdk. size (ha)	Max pdk. size (ha)	Av. pdk. size (ha)	Effective area (ha)
1	Pivot/travelling gun	59	0.92	4.37	2.58	152
2	Pivot	44	2.96	7.59	4.29	189
3	Pivot	57	2.75	16.54	7.08	404
LUDF	Pivot	21	1.78	9.93	6.22	162
5	Rotary boom	35	4.10	12.09	5.77	202
6	Border-dyke/sprinkler	49	1.38	46.03	8.92	437
7	Rotary boom	51	1.14	14.32	7.10	362
8	Pivot/travelling gun	48	2.22	18.86	12.63	606
9	Rotary boom	43	0.56	13.41	9.81	422
10	Border-dyke/sprinkler	62	2.32	8.80	5.60	347
Totals		469				3302

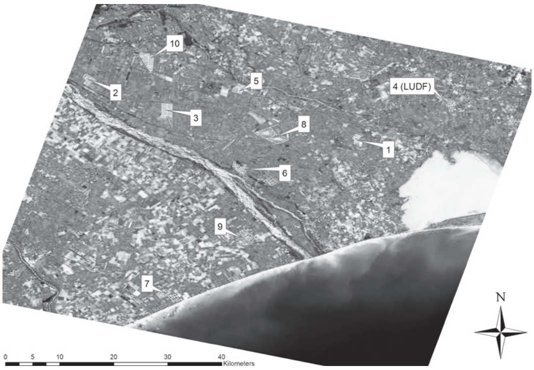

Figure 1 Geographical distribution of participating farms in the Canterbury region, overlaid over a SPOT-5 satellite image (Image 6, 15 March, 2009).

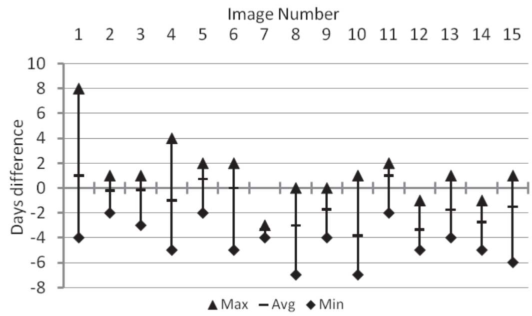

Figure 2 Number of days difference between image date (day zero) and date for commercial data acquisition.

Table 2 Image acquisition dates for the 2008 and 2009 milking seasons in Canterbury, satellite sensor and pixel size (m), the number of commercial farms providing validation data and the number of paddocks in the validation for each image.

Image No.	Milking season	Image date	Days since winter solstice	Satellite sensor: pixel (m)	Farms providing data	No. of LUDF paddocks	No. of commercial paddocks
1	2008	14/08/08	54	5:10	7	14	47
2	2008	21/10/08	122	5:10	9	5	215
3	2008	12/01/09	205	5:10	7	8	164
4	2008	8/02/09	232	4:20	6	16	111
5	2008	1/03/09	253	4:20	7	18	157
6	2008	15/03/09	267	5:10	9	20	224
7	2009	8/08/09	48	5:10	2	15	33
8	2009	25/08/09	65	4:20	8	17	100
9	2009	8/09/09	79	5:10	7	19	126
10	2009	20/09/09	91	4:20	6	18	73
11	2009	25/10/09	126	5:10	4	19	73
12	2009	25/11/09	157	5:10	3	20	-
13	2009	5/12/09	167	5:10	4	16	83
14	2009	20/02/10	244	5:10	4	17	58
15	2009	8/03/10	260	5:10	4	18	68

in the final analysis dataset: a) within the calibration range for the model (1000 to 3500 kg DM/ha), b) collected within ± 3 days of image acquisition and c) visually assessed within the context of each individual farm to ensure farm practices, such as grazing, topping, rolling, and re-fencing, had not introduced additional errors. Initially there were 2737 paddock-average pasture cover values from commercial farms that had corresponding satellite derived estimates, of which 2705 were within the calibration range, and 2103 were within the ± 3 days of image acquisition. A total of 271 values were linked to farm activities as defined earlier in this paragraph or data entry errors, and were therefore excluded.

Image 10 behaved quite differently to all other images in relation to slope and intercept coefficients of the regression for both commercial and LUDF data (Table 3). This may be related to atmospheric effects on the short wave infrared band (SWIR). At this stage temporal analyses of atmospheric effects have not been evaluated, and the image was excluded from the current analysis as it did not contribute to the understanding of commercial vs. LUDF data variability. Similarly, the decision was made to exclude all data from property No. 10. This property was only sampled in the first season (2008), and between mid October and mid February of that season it suffered from water shortages, limiting the ability to irrigate.

Analysis

The overall regression represents the theoretical view of how the model has performed. However, the farmer wishes to know how well these results can be applied in a practical setting, and therefore is more interested in

Table 3 Statistical summary of individual image regressions and ranking coefficient of LUDF and commercial farm data (growth rate corrected to date of image) vs. satellite estimates and combined regressions.

			LUDF vs. Satellite					Commercial data vs. Satellite				
Milking season	Image date	Image No.	R^2	*RSE	Intercept	Slope	Rank coeff.	R^2	RSE	Intercept	Slope	Rank coeff.
2008	14-Aug-08	1	0.87	212	-104	0.787	0.74	0.72	244	366	0.716	0.74
2008	21-Oct-08	2	0.92	91	144	0.820	0.40	0.74	155	708	0.615	0.74
2008	12-Jan-09	3	0.78	111	820	0.604	0.64	0.61	128	949	0.497	0.64
2008	08-Feb-09	4	0.88	93	435	0.686	0.76	0.51	161	911	0.471	0.67
2008	01-Mar-09	5	0.89	126	734	0.618	0.85	0.72	192	857	0.604	0.82
2008	15-Mar-09	6	0.88	147	237	0.805	0.85	0.84	186	373	0.812	0.81
2009	08-Aug-09	7	0.86	115	378	0.690	0.84	0.66	131	629	0.474	0.68
2009	25-Aug-09	8	0.69	243	59	0.785	0.59	0.78	205	167	0.821	0.68
2009	08-Sep-09	9	0.85	244	251	0.828	0.75	0.80	158	632	0.634	0.75
2009	20-Sep-09	10	0.82	192	117	0.932	0.71	0.73	283	257	1.140	0.72
2009	25-Oct-09	11	0.97	53	487	0.710	0.95	0.72	193	605	0.696	0.63
2009	25-Nov-09	12	0.79	113	821	0.574	0.v71	No data within ± 3 days of image				
2009	05-Dec-09	13	0.84	99	894	0.518	0.71	0.59	112	1139	0.368	0.76
2009	20-Feb-10	14	0.84	112	829	0.582	0.75	0.83	145	697	0.664	0.79
2009	08-Mar-10	15	0.91	111	458	0.675	0.88	0.83	137	535	0.661	0.74
Arithmetic mean of image values			0.85	138	437	0.708	0.74	0.72	173	630	0.66	0.73
StDev			0.07	58	322	0.12	0.13	0.10	47	277	0.19	0.07
All-Combined			0.73	200	504	0.68		0.71	201	571	0.68	

*Residual Standard Error

how well the model will predict results at a single point in the growing season. We therefore analysed all data and data for individual image dates.

The validation analysis has been previously described by Mata *et al*. (2010), and was based on three criteria: a) regression of predicted vs. observed pasture cover; b) the percentage of paddocks within each farm where satellite predictions were within ± 400 kg DM of the RPM estimate, c) the satellite's ability to rank paddocks similarly to the RPM, based on Kendall's rank order correlation (Abdi 2007), a non-parametric test to measure the correspondence between two rankings. The assessment of the paddock ranking capability was based on the following classification of correspondence: a) strong: greater than 0.6, b) medium: 0.60 to 0.50 and c) weak: less than 0.50. All statistical analyses were carried out using Systat statistical software (Systat Ver. 12, 2007, Systat Software Inc., www.systat.com).

Results

For the overall LUDF regression across all images, the coefficient of determination (R^2) was 0.73, with a residual standard error (RSE) of 200 kg DM/ha. Table 3 presents the statistical summary for the individual images and for the combined regression. Between images, the R^2 ranged from 0.69 to 0.97 and the RSE from 53 to 244 kg DM/ha, with arithmetic means of 0.85 and 138, respectively. Slope ranged from 0.51 to 0.93 indicating a level of variability in the performance of the model.

Kendall's mean ranking coefficient was 0.74 ± 0.13 indicating a strong correspondence between rankings from observed and predicted data. The ranking coefficients for the individual image dates ranged from 0.40 to 0.95. The low value relates to Image 2, where only five paddocks were available due to cloud interference, the PCR was below 800 kg DM/ha and there was a poor spread of paddocks within this range.

Seventy-eight percent of paddocks sampled were within ±400 kg DM/ha, from a total of 240 satellite predictions for the LUDF farm. Only Image 1 and Image 8 had fewer than 75% of paddocks within this margin. These images were acquired early in the milking season (mid August) and may have been partially affected by frost, but they both had high R^2 and ranking coefficients. Analysis of the data from the commercial farms showed that Image 1 and Image 8 were not abnormal in relation to the percentage of paddocks within ±400 kg DM/ha.

Finally, while the R^2 values for LUDF were constant throughout the milking season across both years, the coefficients for slope, intercept and the RSE tend to show a well defined sigmoid curve across the season, supporting the suggestion of seasonally dependent between image variability.

The overall regression between commercial data and satellite predictions had an R^2 of 0.71 and an RSE of 201 kg DM/ha, indicating that the overall performance of the commercial data was similar to that of the LUDF data. However, analysis of the between image variability (Table 3) showed a lower range in the individual R^2 (0.51 – 0.84) and RSE (112 – 224) values indicating a lower percentage of the variability accounted for and a somewhat larger RSE for the best performing farms. The mean ranking coefficient for the 47 commercial-farm:satellite comparisons was 0.73 ± 0.10, ranging from 0.45 to 0.90. In over 90% of comparisons, the Kendall ranking coefficient showed a strong correspondence between farmer and satellite rankings. In four cases with weak to medium correspondence, the PCR, determined either from the farmer or satellite data or both, was below 800 kg DM/ha.

The overall percent of paddocks sampled that were within ±400 kg DM/ha was 84 % and ranged from 30 to 100%. Only three farms had a single event of a value below 50% and these occurred for different properties and in different image dates.

Discussion

Researchers have argued for more than 30 years that regular monitoring is crucial to improving management in order to drive productivity and profitability in the dairy industry (Thompson & Blackwell 1999; Thomson *et al*. 2001). However, over this time the adoption of monitoring tools and practices by the dairy industry in general has been mixed, due primarily to time, labour and skill limitations and the demand of other priorities at key times of the year (Dalley *et al.* 2009) and the confusion with regards to the practical application on-farm (Lile *et al.* 2001; Thomson *et al.*1997). The findings in this study demonstrate that pasture cover predictions from satellites can support pasture management and feed allocation decision making and could become an alternative, or complementary to, current technologies in Canterbury.

The validation analysis of the Canterbury model showed improvements in R^2 (0.73 and 0.71 vs. 0.61) and RSE (200 and 201 vs. 270 and 360) for both LUDF and commercial data respectively when compared to previous models in Waikato. More importantly, the R^2 of the individual images and their arithmetic mean indicate that on an image by image basis, the performance was consistently high and did not show the loss of sensitivity seen in Waikato as the season progressed (Mata *et al.* 2010). The loss of sensitivity in Waikato was associated with periods of reduced PCR. In Canterbury the almost constant post-grazing cover value characteristic of irrigated systems may have minimised the effect accumulated litter on PCR. The ranking coefficient showed very strong correspondence, indicating that farmers could confidently use satellite predictions to select the sequence of paddocks to graze. At LUDF, in the one case where ranking coefficient was poor, only 25% of all paddocks were available for analysis.

However, while the overall performance (R^2 and RSE) of commercial data was similar to the LUDF data, within and between images it showed a higher level of variability. Possibly some of the variability was due to differences in the monitoring skills or tools used by some of the participants willing to volunteer their data, but this cannot be tested. Despite this higher variability, for most of the commercial farms in this trial, the performance of the model would also be sufficient to support grazing management decision making.

Greater variability in the commercial data was expected, because of the interaction between unaccounted seasonal variations, and differences in farm practices and spatial distribution (e.g. soil and microclimate effects). Additionally, this variability may be affected by which farms remain after the exclusion of data that was more than ± 3 days from image acquisition.

However, the fact that all data were corrected to the date of the image using the growth rate (GR) from LUDF, and that any data collected more than ±3 days from the image were excluded would have reduced much of the initial variability.

Correction of the field data to the date of the image prior to validation had not been attempted in Waikato due to a lack of reliable and accessible GR information other than historical growth rate tables. This may explain some of the improvements in overall performance in Canterbury using both the LUDF and the commercial data. The benefit of correcting the field data with a constant GR for each date is seen primarily in the analysis of the combined regressions, and then when sets include data collected both before and after the image date.

The assumption was made that the LUDF GR values would be adequate to apply to the other Canterbury farms, despite their spatial distribution and the effect of soil type differences. We assume that further improvements would be possible in the commercial data if more estimates of GR were available to account for spatial distribution and if the GR was adjusted in relation to the pasture cover in each paddock.

A second dataset of research and commercial data collected in the 2010-11 milking season, where cover predictions were delivered in near-real time to 26 collaborating producers is being analysed and will expand on the findings of this report.

Industry implications are:

Data derived from satellite imagery perform accurately when compared against field data of a high standard.

The variability in performance of the data collected on commercial farms may have been affected by the time gap between collections and by the method of collection.

Improving the timing or regularity of data collection on commercial farms and uniformity of methodology and possibly operator skill would result in higher agreement between satellite and commercial data than was observed in this first trial in Canterbury.

If implemented operationally, Canterbury farmers will have an alternative source of information that addresses the time, labour, and skill constraints of farm data gathering. This information will be free of operator bias, will not physically affect the pasture during collection and will be uniformly implemented at the regional scale, allowing better within and between farm comparisons.

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