Validation of a satellite pasture measurement system

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Abstract

Satellite imagery of twenty New Zealand dairy farms over the 2011-16 period was obtained, along with farmer-provided measurements of pasture biomass in each paddock during the same time period. Images were matched against corresponding farmer measurements. Normalised Difference Vegetation Indices were computed for the paddocks in the satellite images, and a linear model was fitted between these indices and the farmer-measured biomass for a farm with rigorous pasture measurement. Pasture predictions from the linear model were computed for the remaining farms in the dataset, and were found to have a standard deviation of error of 329 kg of dry matter per hectare, similar to that obtained from the rising plate meter.

Keywords

satellite, pasture, dry matter

Summary Text

To manage you need to measure, but many farmers do not measure their pasture, due to the inconvenience and substantial time requirements. This paper describes the validation of a model that computes pasture dry matter measurements from satellite imagery. Such a tool would enable farmers to make better pasture management decisions without investing time and effort into pasture measurement.

Introduction

Optimal pasture management on a dairy farm provides substantial value to the farmer (Neal et al. 2017). However, for a farmer to manage their pasture optimally, they must measure and record it regularly, and the majority of farmers do not. An LIC survey of 460 dairy farmers (unpublished) indicated that, while two thirds of farmers undertake some form of pasture measurement, only about half did so regularly, and only 36% of those recorded that information electronically. The time required for regular measurement is substantial, and increases proportionally to farm size. Satellite pasture measurement provides a way for farmers to obtain regular pasture measurements with no labour input.

Satellite pasture measurement requires an algorithm to convert imagery into dry matter measurements (Clark et al., 2006; Mata et al. 2010). Vegetation indices are a family of algorithms that measure vegetation in satellite images. The Normalised Difference Vegetation Index (NDVI, Ali et al. 2016) estimates photosynthetic activity by measuring the difference in an area between the absorption of light in the photosynthetically active region (PAR) of the spectrum, and the absorption of light in the near-infrared spectral region. Live green plants absorb solar radiation in the PAR, and reflect near-infrared light. After computing the NDVI for our data, we investigated the relationship between NDVI and dry matter measured by farmers.

The aim of this investigation was to identify a model to use for estimating dry matter in pasture from satellite imagery at paddock level.
Materials and Methods

To produce and validate our algorithm, we used pasture biomass (kilograms of dry matter per hectare, henceforth kg DM/ha) from a farm (henceforth the ground truth farm) with weekly farm walks by experienced plate meter operators, and satellite imagery for that farm. We used similar data from 19 other farms to evaluate the algorithm.

To minimise confounding variables such as terrain and available water, the farms were selected from the Canterbury region of New Zealand. This region is largely flat, and the selected farmers in this region utilised irrigation to ensure year-round availability of water.

Satellite data were obtained from our satellite image provider for the selected farms, for dates from January 2012 to May 2016. These data were mainly from the Sentinel and RapidEye constellations, and contained measurements in the red, green, blue and near-infrared (RGBN) spectral ranges for each paddock of each farm in the dataset. Farmer measurements (kg_DM/ha) were also obtained for the same time range from LIC’s Land and Feed database. Unfortunately, the Land and Feed system does not record the device used to obtain measurements. The two datasets were combined to produce a dataset that allowed us to use farmer measurements to evaluate satellite estimates.

Farmer measurements tended to be weekly at their most frequent, and satellite measurements were increasingly scarce for years prior to 2017. For example, one farm in our analysis was imaged three times in December 2014, seven times in December 2016, and 31 times in December 2017. Most farms are now imaged daily, though cloud still restricts the number of useful images. This meant that intersections between satellite and farmer measurements were rare; only 239 paddock measurements were available for the ground truth farm.

To increase the size of our ground truth dataset, we allowed a one day gap between measurements from the two systems, which produced a total of 623 records. We computed the NDVI for the mean of the spectral measurements for each paddock. We identified a large number of points where paired farmer dry matter measurements and NDVI results did not fit the relationship that most of these pairs exhibited. Inspection of the satellite imagery on and around the dates in question identified two main sources of this divergence. The first was the window of time between the satellite image capture and the farmer measurement; the paddock could be grazed during this period, creating a substantial mismatch between the two measurements. The second was cloud – when cloud in an image obscured the farm being measured, an accurate pasture measurement could not be derived. Sixty-eight paddock records were removed from the ground truth dataset, leaving 555 records for model construction.

A linear model was fitted to the paired dry matter and NDVI data from the ground truth farm in R (R Core Team, 2018) to predict dry matter from NDVI; the dry matter was the response variable, and NDVI the predictor.

Results

The standard error of the residuals for the linear model was 335 kgDM/ha.

The response of NDVI to increased dry matter began to diminish between 2,500 and 3,000 kgDM/ha. A literature review identified that such saturation was a property inherent to NDVI and one paper contained a correction (RVI) that could be applied to NDVI to mitigate this effect (Gu et al, 2013). When we applied this adjustment to our data and refitted the model, the standard error of the residuals for the RVI-based model was 326 kgDM/ha.
This model was then applied to a test set comprising the 19 remaining farms in the data. The standard deviation of error for the model predictions was 329kgDM/ha. Figure 1 shows a comparison of farmer-measured biomass and the biomass predicted by the model.

Figure 1: Comparison of farmer-measured and satellite-predicted biomass. No outlier values have been removed.

Including the satellite measurements within one day of the plate meter measurements did not have a significant effect on the accuracy of the model on the test data (an F test comparing the standard deviations of error for exact-day and within-one-day models returned a p-value of 1, indicating those values were not significantly different).

Discussion

The observed standard deviation of error for satellite prediction compared well with that reported in the literature for the rising plate meter; for example, L'Huillier & Thomson (1988) report a standard deviation of error of 311-610 kg DM/ha for the rising plate meter, and King et al. (2010) report a rising plate meter RMS error ranging from 441 to 773 kg DM/ha across five regions of New Zealand, and also give a comparison to the CDAX Pasturemeter (RMS range 520 to 668 kg DM/ha). For our results above, the RMS error is very similar to the standard deviation of error (within one kg DM/ha), due to minimal bias. This provides an indication that satellite-based predictions of pasture dry matter could be used as a pasture measurement tool on-farm.

Mata et al. (2011) reported an overall RSE of 200 kg DM/ha for satellite estimation in their work in the Canterbury region; their algorithm utilised at least one spectral band unavailable to us, and also data external to the satellite image. This indicates that there could be room to improve our current system.
Satellite estimation of pasture dry matter was offered as a commercial service in Australia until recently (http://www.pasturesfromspace.csiro.au/).

In Figure 1, we have not removed any outliers from the test dataset, to give an indication of the distribution of these points. These outliers are clearly distinct from the main relationship between prediction and measurement. There are a number of factors that interfere with the relationship between plate meter measurement and satellite estimation (Mata, 2011). Cloud and grazing are the main sources of these deviations.

The saturation of the NDVI measurement, beginning in the 2,500-3,000 kgDM/ha range, could limit its effectiveness on farms that regularly run paddock covers over 3,000kgDM/ha.

With the increased quantity of satellites in orbit, it should be increasingly easy to match satellite measurements against each farmer measurement, and thus gather more comprehensive datasets to build new models or refine existing ones.

The availability of regular pasture measurement data, without an onerous time investment, would give farmers the capability to make informed feeding decisions for their herds, and thus improve the productivity of their farms.

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References


CONFLICTS OF INTEREST

Livestock Improvement Corporation is currently offering a satellite pasture measurement service (SPACE™) based in part on this work.