Photogrammetry for assessment of pasture biomass

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Abstract

New tools are required to provide estimates of pasture biomass as current methods are time consuming and labour intensive. This proof-of-concept study tested the suitability of photogrammetry to estimate pasture height in a grazed dairy pasture. Images were obtained using a digital camera from one site on two separate occasions (May and June 2017). Photogrammetry-derived pasture height was estimated from digital surface models created using the photos. Pasture indices were also measured using two currently available methods: a Rising Plate Meter (RPM), and Normalised Difference Vegetation Index (NDVI). Empirical pasture biomass measurements were taken using destructive sampling after all other measurements were made, and were used to evaluate the accuracy of the estimates from each method. There was a strong linear relationship between photogrammetry-derived plant height and actual biomass (R^2=0.92$_{May}$ and 0.78$_{June}$) and between RPM and actual biomass (R^2=0.91$_{May}$ and 0.78$_{June}$). The relationship between NDVI and actual biomass was relatively weaker (R^2=0.65$_{May}$ and 0.66$_{June}$). Photogrammetry could be an efficient way to measure pasture biomass with an accuracy comparable to that of the RPM but further work is required to confirm these preliminary findings.

Keywords: Normalised Difference Vegetation Index (NDVI), optical sensors, reflectance sensor, Rising plate meter, Structure-from-motion

Introduction

Accurate estimates of biomass in rotationally grazed pastures enable dairy farmers to prepare feed budgets for their farms that maximise the utilisation of feed offered by reducing wastage or overgrazing. This process allows for enough forage to be available for cows to feed throughout the year by providing information for decisions on rotation lengths, supplementary feeding requirements, nitrogen fertiliser use and conservation. Increasing the accuracy of pasture biomass estimates also increases dairy farm operating profits by improving knowledge of pasture availability. This allows feed supply and demand to be better matched resulting in less under and over feeding, higher milk production and optimised post grazing residuals to maximise pasture regrowth (Beukes et al. 2015).

When choosing a pasture measuring method for dairy farmers, it is important that the device: is easy to use; can provide updates within 24 hours of measurement; collects data accurately and quickly; data are easily uploaded, is low maintenance; and has been calibrated for ryegrass/clover swards (Eastwood & Dela Rue 2017). The most commonly used methods to estimate biomass on dairy farms are sward height and rising plate meters (RPM). However, varying degrees of success have been reported relating sward height to actual biomass (Haultain et al. 2014) or RPM to actual biomass (L'Huillier & Thomoson 1988) in ryegrass-based pastures. Both methods also require calibration, have some margin of error, and are time consuming. An alternative approach is to use optical reflectance sensors to derive vegetation indices such as Normalized Difference Vegetation Index (NDVI), which has been related to biomass (Wigley et al. 2017). However, reflectance indices such as NDVI saturate as leaf area index values exceed 4–6 (Lamb et al. 2002) and biomass increases above 4000 kg DM/ha (Trotter et al. 2010; Edirisinghe et al. 2011), hindering the relationship. The C-Dax Rapid Pasturemeter is another sensor-based technology that is towed behind a vehicle across a paddock at up to 20 km/h and takes 200 measurements per second. It provides farmers with fast, accurate estimates of pasture biomass with similar accuracy to the RPM (Yule et al. 2010). The disadvantages of this technology are that it needs calibration (King et al. 2010) and, although it may be faster than walking a paddock, it is still time consuming.

Photogrammetry is a remote-sensing technology that can provide regular estimates of plant heights with minimal time and labour by extracting relevant data from digital surface models (Wolf et al. 2000). Plant-height models have been found to provide robust total biomass estimates for summer barley (*Hordeum vulgare*) (R^2 = 0.80–0.82) (Bendig et al. 2015), and strong and significant correlations were found for plant height from crop surface models to plant height

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ground truth for legumes and some rarely used dicots (R^2 = 0.97) (Roth & Streit 2017). Grassland height from satellite images using reflectance in visible and near-infrared bands has also been assessed (Cimbelli & Vitale 2017). Photogrammetry has also previously been used to measure smooth brome (*Bromus inermis*) pasture biomass overseas (Cooper et al. 2017). Photogrammetry from moving platforms (i.e. a centre pivot) using the 'structure-from-motion' method (Cooper et al. 2017) could be a cost-effective and efficient way for dairy farmers to measure pasture biomass as digital cameras are often cheaper and more readily available than optical sensors, and easier to operate than remotely piloted aircraft systems (RPAS) or unmanned aerial vehicles (UAVs). Structure-from-motion is a new passive method that uses a computer vision technology to take overlapping 2D images, such as those captured with photogrammetry, to create 3D point clouds (Snavely et al. 2006). However, the accuracy of this method to estimate biomass of ryegrass dairy pastures in New Zealand has not been tested.

Thus, the objectives of this study were to: (i) undertake a proof-of-concept study to assess the suitability of determining pasture height from proximal photogrammetry through structure-from-motion with optical sensors (a digital camera attached to the back of a truck ~4 m above soil surface to mimic a centre pivot); and (ii) compare this new method with biomass estimates made using RPM and NDVI measured with an active optical reflectance sensor.

Materials and Methods

Site description

The experiment was conducted at the Lincoln University Dairy Farm (43°38'23.69"S, 172°26'34.66"E, 17 m elevation), Lincoln, Canterbury, New Zealand. The pastures on farm are a mix of perennial ryegrass (*Lolium perenne*) and white clover (*Trifolium repens*). Average annual precipitation from 1960–2016 was 611 mm, ranging from 305 to 909 mm (National Institute of Water and Atmospheric Research n.d.). On the farm, precipitation was supplemented with approximately 500 mm of irrigation per annum (Moir et al. 2007). The daily average temperature during the months when the experiments took place (i.e. May and June 2017) was 7.3°C. (Temperatures were recorded at Broadfields Meteorological Station, which is located approximately 12 km north east of the experimental site).

Three paddocks representing different stages after grazing (and, therefore, three different biomass yields) were selected based on time after grazing and visual pasture height (Low, Medium and High) and confirmed with a whole paddock RPM measurement (data not shown) for both sampling events.

Sampling

Sampling occurred in May and June 2017, respectively. Both sampling days were cloudy with no wind. The same biomass variables were measured on both occasions:

- actual biomass yield from manual clippings (kg DM/ha);
- estimated biomass yield (kg DM/ha) and biomass height derived from a RPM (F200, FARMWORKS, New Zealand);
- estimated biomass height (cm) from photogrammetry (see details below); and
- NDVI from optical sensor measurements from GreenSeeker (Trimble, Sunnyvale, California, USA).

On each sampling occasion, sampling occurred in 15 sampling quadrats (0.5 x 0.5 m), 1 m apart, along a straight 22.5-m marked path. The locations of the quadrats, along with the start and stop spots along the sampling path and points on either side of the truck tyres, were recorded with GPS. During the second sampling event, ground control tiles were placed alternating above and below the centre line of the sampling areas between the tyre tracks to provide a better reference for stitching together the images in post-processing.

For both sampling events, in each paddock, at each sampling quadrat, measurements were taken in the following order: NDVI, RPM, pre-manual sampling photogrammetry, manual sampling for determination of actual biomass, and post-manual sampling photogrammetry measurements. Photogrammetry measurements were made by securing the camera (Canon Powershot SX 260 HS, 12.1 Megapixel, resolution: 4256 x 2832 and focal length: 4.5 mm) to the back of a truck and using a Canon Hack Development Kit to capture true colour images ~ 4 m above the soil surface of the biomass between the tyre tracks. The camera was positioned nadir to the ground. This arrangement was used to mimic collecting data from a centre pivot irrigator. During sampling, the truck drove along the pre-established path in each paddock. A photograph was taken every 0.5 m manually along the 22.5 m strip which allowed for 80% overlap between images, resulting in 45 pictures for each paddock. The truck was stationary during data capture. Images were captured over a short period of time to ensure consistent light conditions as variation in lighting conditions can effect model quality (Miller et al. 2015). Sward height (cm) was derived from the photogrammetry data using the before and after pasture cutting images. The images from each paddock were stitched together using Pix4Dmapper (Pix4D, Lausanne, Switzerland) to construct a georeferenced 3D model. A 3D point cloud processing software CloudCompare (version 2.9 beta) was then used to calculate biomass height within in each paddock.

Normalized Difference Vegetation Index measurements were made at each sampling quadrat with a handheld GreenSeeker as described by Wigley et al. (2017).

A RPM was used to estimate biomass yield (kg DM/ha) based on pasture density at each sampling quadrat.

Fifteen manual biomass samples were collected within the 0.5 m × 0.5 m sampling quadrats to determine "actual biomass". Hand shears were used to cut the biomass to the soil surface. The fresh biomass samples were weighed, and a subsample was collected and dried for 72 hours at 65°C. The mass of the dried subsamples was used to determine dry matter yield as kg DM/ha.

Data analysis

Using R Statistics, a one-way ANOVA was used to detect differences in biomass between low, medium and high paddocks (using the *aov* function). Fisher's protected least significant difference (LSD) test was used to separate means for each factor when ANOVA gave a P value of <0.05 (using the *lsmeans* package). Linear regressions were calculated using Microsoft Excel (2013) to relate actual biomass to biomass estimates from each method using data from each paddock individually (Low, Medium, and High) and all together.

Results

Paddock biomass classification

The three paddocks were designated 'Low', 'Medium' and 'High' height based on a whole-paddock RPM measurement (data not shown). In May, detailed measurements of the sampling areas using an RPM indicated that the Low paddock had the lowest mean DM (1728 kg DM/ha) and the High paddock had the highest mean DM (4481 kg DM/ha). The Medium paddock had a mean DM of 1797 kg/ha but this value was not significantly different (P>0.05) from that of the Low paddock, Table 1. Biomass estimates from the RPM were between 802 to 1566 kg DM/ha greater than the actual biomass measurements (determined from quadrat cuts). The mean actual biomass of the Medium paddock was, in fact, lower (881 kg DM/ha) than that of the Low paddock (926 kg DM/ha) but, again, the difference was not significant (P>0.05). The heights derived from the RPM were also relatively higher in all measurements than those derived from photogrammetry (Table 1). Significant differences between the Low, Medium and High paddock were found only when using NDVI (Table 1).

In June, all methods showed that biomass estimates from the Low paddock were less than those from the Medium paddock, which were less than those from the High paddock (all P≤0.05, Table 1).

Relationship between actual biomass and estimated pasture height

When all paddocks were analysed together, actual biomass obtained from clippings and photogrammetry-derived pasture height were strongly related with relatively high R^2 values (≥0.78) between the variables on both sampling occasions (Figure 1A and B, Table 2). Weaker relationships between the variables were noted when only data within individual paddocks were considered. The actual biomass measurements were strongly related to the RPM estimates of biomass on

Table 1 Mean values for each of the methods used to estimate pasture biomass. P-values represent the ANOVA test and paddock pasture measurements for each sampling date that do not share a letter are significantly different at P≤0.05

Sampling date/Method	Paddock			
	Low	Medium	High	P-value
May 2017				
Actual biomass from clippings (kg DM/ha)	926 a	881 a	2915 b	<0.001
Estimated biomass from RPM (kg DM/ha)	1728 a	1797 a	4481 b	<0.001
Estimated height from RPM (cm)	9 a	9 a	28 b	<0.001
Estimated height from photogrammetry (cm)	4 a	5 a	14 b	<0.001
NDVI from optical sensors	0.55 a	0.71 b	0.91 c	<0.001
June 2017				
Actual biomass from clippings (kg DM/ha)	1316 a	2787 b	3219 c	<0.001
Estimated biomass from RPM (kg DM/ha)	1762 a	3406 b	3920 c	<0.001
Estimated height from RPM (cm)	9 a	21 b	24 c	<0.001
Estimated height from photogrammetry (cm)	5 a	14 b	18 c	<0.001
NDVI from optical sensors	0.86 a	0.80 b	0.89 c	<0.001

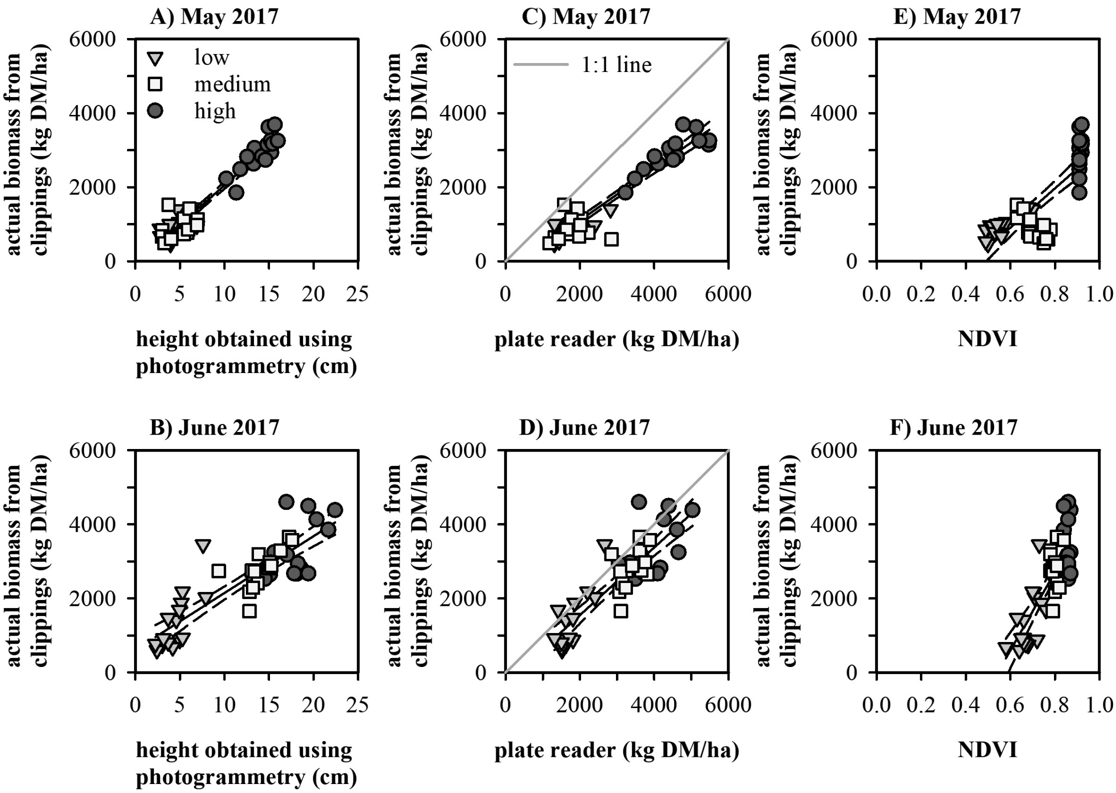

Figure 1 Relationship between actual biomass and pasture height derived using photogrammetry (A_{May} and B_{June}), or biomass estimated using an RPM (C_{May} and D_{June}) or using the NDVI (E_{May} and F_{June}). Measurements from all paddocks (High, Medium and Low) are included with a linear best fit line (solid black) and 95% confidence intervals (dashed black lines). The solid grey lines in C and D show a 1:1 relationship between the variables. Each point represents a quadrat.

Table 2 Linear regression equations and R^2 values for relationship between height measured via photogrammetry, RPM and NDVI, and actual biomass measured by clipping.

Method	Paddock pasture height	May		June	
		Equation	R^2	Equation	R^2
Photo. Height	Low	y = 11741x + 398.78	0.27	y = 31766x – 126.16	0.64
	Med	y = 9049.6x + 443.92	0.17	y = 17062x + 379.02	0.44
	High	y = 23576x + 361.80	0.71	y = 17334x + 196.49	0.30
	All	y = 212.46x + 70.16	0.92	y = 155.49x + 573.59	0.78
RPM	Low	y = 0.4023x + 230.26	0.38	y = 1.3906x + 1134.1	0.68
	Med	y = 0.0549x + 782.07	0.01	y = 0.8315x + 45.335	0.26
	High	y = 0.0607x + 19.397	0.72	y = 0.7138x + 521.3	0.31
	All	y = 0.7014x + 297.93	0.91	y = 0.9171x + 304.06	0.78
NDVI	Low	y = 3591.1x + 1059.1	0.70	y = 8615.1x + 4536.5	0.39
	Med	y = -4581.1x + 4136.4	0.52	y = 5392.3x + 1519.5	0.03
	High	y = 49040x – 41874	0.24	y = -28686x + 27989	0.14
	All	y = 5313.8x + 2281.5	0.65	y = 10692x + 5858.7	0.66

both sampling occasions when all paddocks were analysed together (Table 2) but the relationships between the variables were not as strong when analysed within individual paddocks. The R^2 values between the actual biomass and the estimates obtained using RPM were similar to those found between actual biomass and photogrammetry-derived biomass height (Table 2). However, a 1:1 line shows that the RPM overestimated the actual biomass (Figure 1C and D). Of the tested methods, NDVI had the weakest relationship with actual biomass (Figure 1E and F, Table 2). The NDVI values did not vary when biomass was high (Figure 1E and F).

Discussion

This study used photogrammetry coupled with structure-in-motion to estimate pasture height in New Zealand dairy pastures. Our results are consistent with previous work from South Dakota, USA, which showed that grass biomass measurements from photogrammetry images taken from a consumer grade digital camera were of greater accuracy than RPM measurements (Cooper et al. 2017).

The derived values from photogrammetry were strongly related to actual biomass when all paddocks (High, Medium and Low) were analysed together. However, relationships were weak when only one paddock was considered. This result suggests the need for an initial calibration or standardisation for photogrammetry to develop equations that can be used to calculate biomass from height obtained using photogrammetry, similar to the calibration equations developed for the RPM. As well as an initial calibration, a suitable ground reference point will also need to be found to derive pasture height. In photogrammetry, the measured point height is subtracted from the ground surface height (Bareth et al. 2016); however, this approach is impractical since farmers do not allow stock to graze down to bare earth. This preliminary study did not address how to incorporate a ground reference for remotely sensed photogrammetry but the distance from the camera to the ground could be pre-determined to provide an estimated ground reference if the camera were deployed on a centre pivot irrigator. One option for incorporating a ground reference would be to develop a digital terrain model for a paddock, which could be updated (up to 10 times a year) after each occasion where the paddock was grazed (if it is assumed that the residual sward height is negligible or ignored in the photogrammetric approach). Developing a method to get a suitable ground reference is a topic for future work.

The results of this proof-of-concept study suggest photogrammetry has potential to be of use by the New Zealand dairy industry, although there are some issues that need to be addressed prior to wide-spread adoption. While the photogrammetry data collected was strongly related to actual biomass, there are many factors that may affect the use of photogrammetry for determining biomass in pastures. The proportion of ryegrass/white clover and different ryegrass/white clover cultivars could affect the relationship between actual biomass and plant height derived from photogrammetry and is an area for future research. Problems could be caused by wind with high biomass as ideally, the vegetation surface should not move during surveying (Grenzdörffer 2014; Hämmerle & Höfle 2016). Likewise, biomass that is unevenly distributed and sparse is difficult to measure with photogrammetry. Under these conditions, plants that are lower than the manual reference, newly sown or have been trampled by cattle, may not be accurately determined using photogrammetry as the vegetation cover is low and canopy surface is too small to form a closed canopy (Grenzdörffer 2014). Thus, applying the methods used in the current experiments to different conditions may not yield the same strong relationships between actual biomass and plant height from photogrammetry.

The approach used during the current experiment where a swath of the pasture was measured using photogrammetry has both benefits and limitations. The benefits are that it is easy and repeatable. However, it is difficult to assess whether the biomass in a 22.5-m swath of pasture is representative of the biomass throughout a paddock. The observed variability in pasture height could be related to data collection (i.e. error in the instrumentation), the environment (i.e. hummocks and hollows on the soil surface), or a combination of both factors. More measurements over a greater area, as well as gathering some ancillary data to determine sources of variability (such as instrumentation, environment, or both) are needed to address these issues. Future studies should consider developing empirical calibrations between the image data and ground data to predict pasture biomass, which may help reduce error (Álvarez et al. 2010). Experimental error from the sampling method is an important source of variation and, therefore, the error attributed to the instrument and the errors attributed to the methods used to collect the data should be understood and quantified (Hutchings 1991).

The incorporation of commonly used methods for determining biomass, RPM and NDVI, served as a means of comparisons with photogrammetry in the current study. The strong relationships between actual biomass and RPM were similar to the relationships between actual biomass and height estimates made using photogrammetry. It was compelling that the RPM estimates of biomass as kg DM/ha were similar to actual biomass from clippings in June 2017, but RPM overestimated biomass in May 2017 by up to ~1000 kg DM/ha. Such inaccuracies could have substantial economic consequences for farmers (Beukes et al. 2015). Some of this overestimation from the RPM may be attributed to the use of a standard calibration for the RPM which can be corrected with site-specific calibration. Even if a site-specific calibration were used to improve the accuracy of RPM, it is still labour intensive compared to photogrammetry which can be measured remotely.

Photogrammetry-derived biomass estimates were more accurate than NDVI measurements. NDVI is a proxy for biomass via its determination of greenness. Therefore, plant phenology and plant health affect NDVI and measurements are likely to saturate at high biomass values (Hobbs 1995; Edirisinghe et al. 2000; Edirisinghe et al. 2011). This limitation was apparent in the current study where NDVI values saturated between ~0.8 and ~0.9. When the NDVI values were saturated, they did not vary while dry matter yields varied ~1500–2500 kg DM/ha. This finding suggests the use of NDVI is limited to estimating biomass in grazed pastures when biomass is low. Similar results have been reported for summer barley (Bendig et al. 2015) and tropical grass (*Cenchrus ciliaris*) (Mutanga & Skidmore 2004). Although the Green Seeker instrument used for NDVI estimates is widely available and easy to use, it cannot be suggested as a proxy for biomass for dairy pastures based on our results.

An advantage of photogrammetry is that it can use a consumer-grade camera and has the potential to be deployed on existing farm infrastructure like an irrigator. If situated on a centre pivot irrigator, the camera could be on an automatic timer attached to a centre pivot so it could take photos/measurements remotely and automatically. Future studies should explore how to optimise placement of the camera to improve the accuracy of the photogrammetry results. In the current study, the camera was positioned nadir to the ground, but differences in view angles may lead to differing results. Images captured from more oblique positions may result in non-homogeneous point densities compared to a nadir viewpoint. Since variation in plant height increases with increases in crop surface roughness, this variation will be greater with nadir views. In contrast, oblique views may smooth the surface roughness, resulting in less variation in plant height data (Bareth et al. 2016). This issue also has implications for accuracy in multi-species pastures. Our study was preliminary and, therefore, we did not experiment with camera deployment but we acknowledge that experimentally induced factors like camera placement, could influence the accuracy of the photogrammetry-derived biomass height. Using a consumer-grade camera as a passive sensor also has some potential issues. The stereoscopic assessment through sequential images from the cameras are sensitive to changes in illumination, suggesting that research is required to identify the error in height assessment when light conditions are not stable (Verger et al. 2014). Another limitation of this method is the complexity of the data analysis for non-specialist users. To estimate biomass height from the images captured using photogrammetry, post-processing of the data is required; this study used Pix4D and CloudCompare software. Before photogrammetry will be adopted as a tool for farmers, the data management and interpretation must become less technical and more accessible.

Relevance/Practical implications/Conclusions

This was a preliminary study evaluating the use of photogrammetry to estimate pasture biomass in a New Zealand dairy pasture. We completed a systematic comparison of currently used methods (RPM and NDVI) and photogrammetry with manually sampled pasture biomass over two sampling dates, in three pastures on each date, with varying pasture biomasses. While this study was preliminary, our results suggest photogrammetry-derived height could be used to estimate biomass with accuracy comparable to that of the commonly used rising plate meter. Cameras could be mounted onto a platform that regularly moves across the paddock such as an irrigator making the measurements less labour intensive compared to RPM. However, more research is needed to test the best way to deploy the camera, and to evaluate how environmental and pasture conditions including different pasture compositions, cultivars and ages affect the pasture biomass estimates.

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