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Evaluating low-cost Lidar and Active Optical Sensors for pasture and forage biomass assessment

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Abstract.

Accurate and reliable assessment of pasture or forage biomass remains one of the key challenges for grazing industries. Livestock managers require accurate estimates of the grassland biomass available over their farm to enable optimal stocking rate decisions. This paper reports on our investigations into the potential application of affordable Lidar (Light Detection and Ranging) systems and Active Optical (reflectance) Sensors (AOS) to estimate pasture biomass. We evaluated the calibration accuracy of the recently released Pulsed Light LidarLite™ against common AOS including the Trimble® GreenSeeker® Handheld and Holland Scientific ACS-470 Crop Circle™ in a Tall Fescue (*Festuca arundinacea*) pasture. We also compared the LidarLite™ sensor against a rising plate meter which has traditionally been used to assess pasture height and density. Finally, we explored the potential for integrating AOS with Lidar to improve biomass estimation accuracies. Both the plate meter and the Lidar sensor were significantly related to Total Dry Matter ($P<0.01$). The Lidar reported a slightly better R^2 (0.75) than the plate meter (0.72). Both AOSs were found to have a significant relationship with TDM ($P<0.01$) with the ACS-470 Crop Circle™ showing a slightly higher R^2 (0.88) than the GreenSeeker® Handheld (R^2=0.80). A number of variable transformations and combinations of both the ACS-470 Crop Circle™, GreenSeeker® Handheld and LidarLite™ were explored. The optimal model was found to be a non-linear transformation of the mean height multiplied by the mean NDVI derived from the ACS-470

Crop Circle™. We have subsequently defined this model as the Non-Linear Height and Reflectance Index (NHRI). The relationship of the NHRI to TDM was found to be significant (P<0.01) with a R^2 of 0.96. Whereas this study investigated two different types of AOS, in order to develop the NHRI, future research should focus on engineering similarly affordable integrated devices which combine height and photosynthetically active biomass sensors.

Keywords.

Lidar, Active Optical Sensor, Greenseeker, Crop Circle, pasture, forage, biomass.

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Introduction

Pasture or forage biomass assessment remains one of the key challenges for grazing industries. Livestock managers require accurate estimates of the grassland biomass available over their farm to enable optimal stocking rate decisions. Improved estimates may increase farm profitability of approximately 10% in Australian beef and sheep enterprises (Henry *et al.* 2013).

There have been several techniques developed and evaluated for measuring pasture biomass over the past two decades which work reasonably well in defined situations. In highly productive dairy pastures, several proximal sensors, mostly measuring height have been developed that successfully estimate available biomass (Yule *et al.* 2010). Satellite based systems have been in development for many years (Smith *et al.* 2011), however a key limitation to remote sensing systems is the restricted acquisition of imagery due to cloud cover. However, in less productive pastures, used for red meat production, the challenge remains to accurately estimate the biomass in highly diverse, mixed species and mixed phenology swards (Trotter 2013).

In recent years the use of active optical sensors for pasture and forage biomass estimation has been explored (Trotter *et al.* 2010; Trotter *et al.* 2012). Simple active reflectance sensors have been used extensively in cropping for improved fertiliser management (Moges *et al.* 2004) and have recently become available as producer affordable handheld devices (e.g. Trimble's GreenSeeker® Handheld). Another class of optical sensor also using narrow wavebands of the electromagnetic spectrum are Lidar (Light Detection and Ranging) systems. The sensors have been used extensively in forestry research (Schaaf *et al.* 2014), however have been too expensive for widespread use outside of a research context for crop or pasture management. Preliminary research suggests that Lidar sensors have the potential to improve the estimation of pasture biomass (Radtke *et al.* 2010; Schaefer and Lamb 2016). However, the instruments used in these studies are not affordable and therefore have not been adopted by producers for everyday on-farm measurements. Like canopy reflectance sensors, the Lidar devices have also now reduced in price with simple modules available for less than $150, including the LidarLite™ from Pulsed Light.

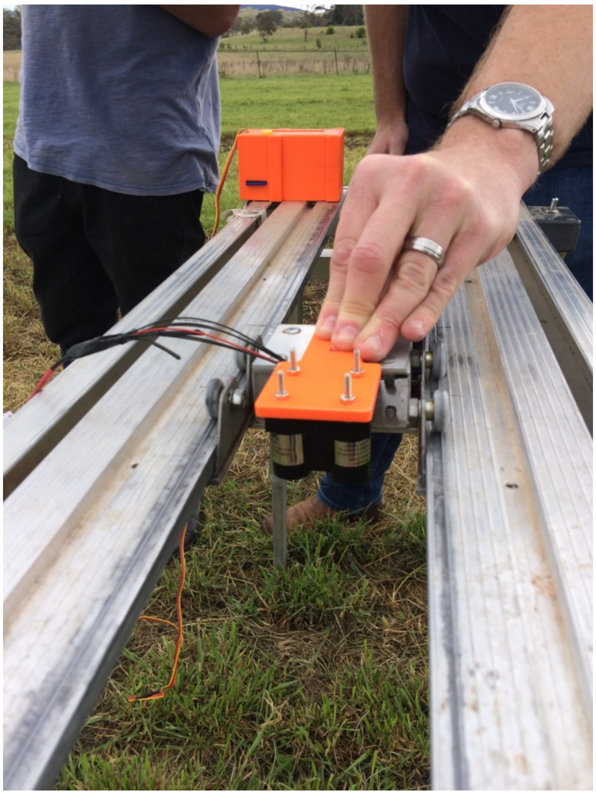

Figure 1. The LidarLite™ sensor mounted on sampling table with data logger.

This paper reports on the potential application of affordable active optical and Lidar sensing systems for estimating pasture biomass. We evaluate the calibration accuracy of the Pulsed Light LidarLite™ against AOS (the Trimble® GreenSeeker® Handheld and the Holland Scientific ACS-470 Crop Circle™) in a Tall Fescue (*Festuca arundinacea*) pasture. We also compare the LidarLite™ sensor against a rising plate meter which has traditionally been used to assess pasture height and density. Finally we explored the potential for integrating AOS with Lidar to improve the accuracy of biomass estimation.

Materials and methods

A Tall Fescue pasture was sampled during Autumn in 2016. The sampling procedure consisted of deploying each sensor over 8 quadrats measuring 0.3m by 0.7m. This quadrat size was selected as the best compromise between the GreenSeeker® and ACS-470 Crop Circle™ footprints when deployed at 1 m from the ground. The GreenSeeker® and ACS-470 Crop Circle™ were mounted on a frame specifically designed to center their footprint and maintain a common deployment height. The LidarLite™ sensor was deployed on a specifically adapted trestle table designed to allow the sensor to be manually moved along a set of tracks and scan a linear footprint along the length of the 0.7 m quadrat (Fig. 1). Three scans were taken along this axis in each quadrat. Each scan line from the Lidar sensor produced an average of 165 height recordings. These measurements reflected the distance from the sensor to the pasture and were subsequently converted into pasture height values by subtracting the measured distance from the sensor to the ground when no pasture was present (87.5cm). The average of the all Lidar readings in a quadrat was calculated for the single Lidar value. After the three proximal sensing systems were deployed, three readings were taken with the plate meter and averaged over the quadrat.

The biomass in each quadrat was then cut to ground and bagged. A sub-sample (> 60 g) of the biomass was taken for sorting into green and dead fractions. The sub-samples and the remaining bulk samples were then oven dried for 48 hours at 70°C. All samples were then re-weighed, with the sub-samples used to determine the composition of green, dead and total biomass and converted to kilograms per hectare.

All data was processed, summarized and graphed in MS Excel with statistical analysis undertaken in JMP.

Results and Discussion

The biomass measurements over the 8 quadrats ranged from a Total Dry Matter (TDM) of 1,567 kg/ha to 6,493 kg/ha (mean = 4,502 kg/ha), a Green Dry Matter (GDM) of 380 kg/ha to 6,022 kg/ha (mean = 3,195 kg/ha). The GDM ranged from 24% to 97% of the TDM (mean = 64%). This represents a pasture sward at the higher end of a rotational grazing program, with the higher biomass quadrats (> 4,000 kg/ha) beyond what would normally be categorized as good levels for animal production. Despite this, the samples do provide an adequate range over which to test and evaluate the various sensors.

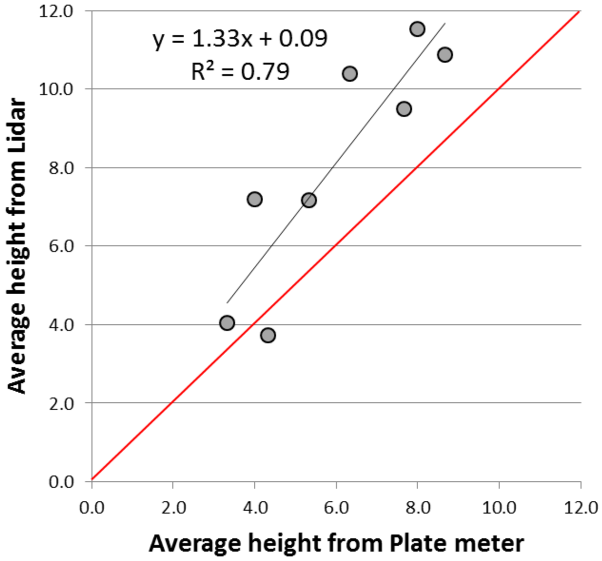

Figure 2. Relationship between the average height from a plate meter and the average height from the LidarLite sensor. Red line depicts the 1:1 line.

Comparing the plate meter and Lidar

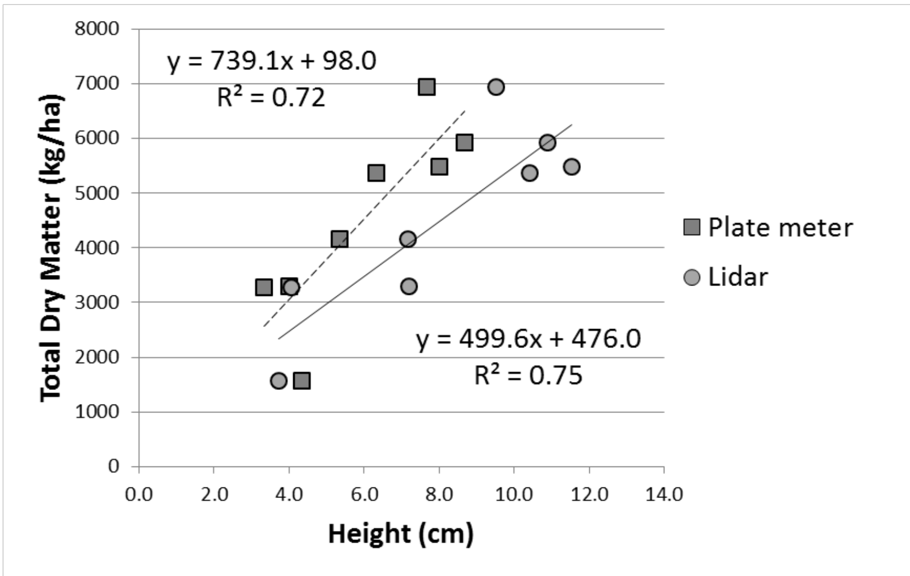

Figure 3 Comparison between the Plate meter and Lidar in terms of the correlation to Total Dry Matter (kg/ha). Both sensors show a similar calibration accuracy.

A significant linear relationship was found between the traditional plate meter and the Lidar sensor ($P<0.01$, $R^2=0.79$). A visual assessment of the correlation (Fig. 2) reveals a non-linear relationship. The transformation (square root) of one of the variables did improve the R^2, however this was only marginal ($R^2=0.82$). The Lidar consistently measured higher values than the plate meter. Our initial hypothesis was that the plate meter would record higher values as it is held up by the tallest parts of the sward whilst the Lidar scans the full profile of the sward, including the areas that are lower than that detectable by the plate meter. However, the plate meter also compresses the sward, which in this study overrode the effect of variability in height. The plate meter has been widely used as a pasture measurement tool for many years because it integrates both a measure of height and the density of the pasture (Trotter *et al.* 2010). The challenge for the Lidar sensor will be its ability to predict pasture biomass without including the effect of sward resistance as provided by the plate meter. This was specifically explored with the comparison of both the plate meter and the Lidar sensor to predict Total Dry Matter (Fig 3). Both the plate meter and the Lidar sensor reported a significant relationship to Total Dry Matter (P<0.01 for both). The Lidar actually reported a slightly better correlation ($R^2=0.75$) than the plate meter ($R^2=0.72$) however this difference is marginal, and we suggest that the two measures are of equal accuracy in this study. The value of the Lidar comes from two aspects. Firstly, it is able to provide at least a similar degree of accuracy to the plate meter but without making

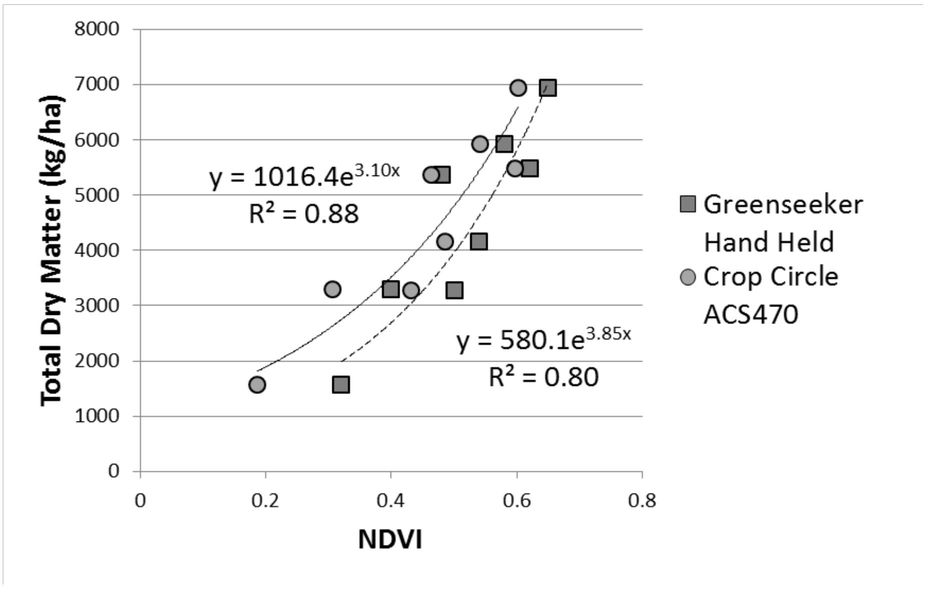

Figure 4 Comparison between the Plate meter and Lidar in terms of the correlation to Total Dry Matter (kg/ha). Both sensors show a similar calibration accuracy.

contact with the pasture sward itself. This means that survey deployment modes such as from a vehicle or even unmanned aerial vehicle could be used to provide equivalent data to the traditional plate meter. Secondly, the Lidar sensor can be deployed rapidly in a survey mode (Schaefer and Lamb 2016), so more representative measures of the entire field can be achieved.

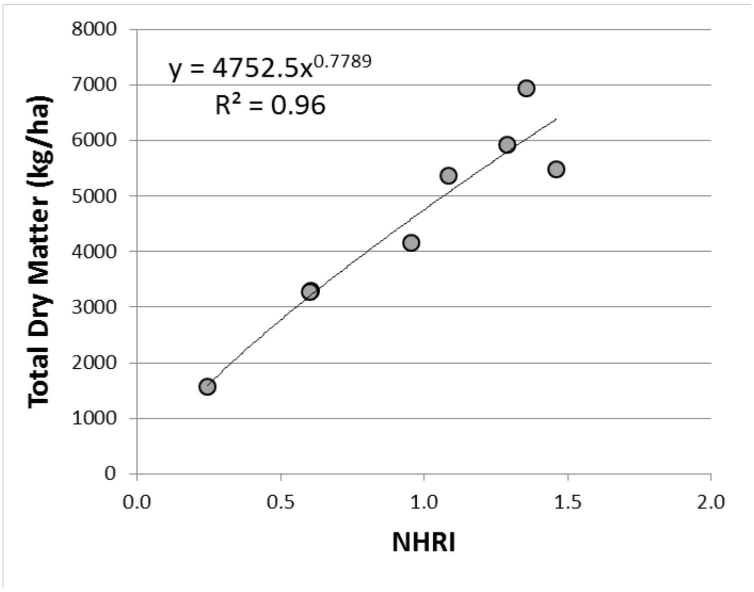

Figure 5 The relationship between the Non-linear Height and Reflectance Index (NLHI) and Total Dry Biomass

Comparing Active Optical Sensors to the Lidar system

An exponential relationship was found between the TDM and NDVI for both the Holland Scientific ACS-470 Crop Circle™ and Trimble® GreenSeeker® Handheld sensors (Fig. 4). Both sensors were found to have a significant relationship with TDM ($P<0.01$) with the ACS-470-Crop Circle™ showing a slightly higher R^2 of 0.88 compared to the Trimble® GreenSeeker® Handheld with an R^2 of 0.80. Experience in the use of these instruments suggests that this may be due to a co-registration issue of sensor foot print to the quadrat dimensions. The quadrat has been designed as a compromise between the ACS-470-Crop Circle™ and GreenSeeker® Handheld foot-prints. As a consequence, the GreenSeeker® Handheld may be penalized as it scans a small area outside the quadrat that may not be representative of the sample taken within the quadrat and misses the longitudinal extremities of the rectangular quadrat. Other samples taken as part of our wider study throughout Australia (n=1,700) have found the Trimble® GreenSeeker® Handheld to have a similar accuracy to the ACS-470 Crop Circle™. In assessing the two classes of sensor, both AOS had a better correlation with TDM than the either the Lidar or Plate Meter achieved.

Integration of Lidar with Active Optical Sensor

We explored the potential for an integrated index derived from both the Lidar Sensor and NDVI data as originally proposed by Schaefer and Lamb (2016). A number of variable transformations and combinations of both the ACS-470 Crop Circle™, Greenseeker® Handheld and LidarLite™ were explored. The optimal model was found to be a non-linear transformation of the mean height multiplied by the mean NDVI derived from the ACS-470 Crop Circle™ (Equation 1), which we have termed the Non-Linear Height and Reflectance Index (HNRI). The correlation of the NHRI to TDM (Fig. 5) was found to be significant ($P<0.01$), and was better correlated with biomass ($R^2 = 0.96$) than both the Height and the AOS sensors alone. The correlation of HNRI with biomass was also an improvement on the R^2 reported by (Schaefer and Lamb 2016) of (R2=0.76). However, the current study is based on only 8 data points compared to Schaefer and Lamb's (2016) more comprehensive sample of 26 plots. The correlation coefficient (R^2) of 0.96 achieved by the NHRI is similar to that reported by Radtke *et al.* (2010) when using a 3D laser scanning approach and creating surface volume estimates for pastures. The addition of a non-linear transformation of height to the multiplication index developed by Schaefer and Lamb (2016) is a simple modification which has been found to improve the relationship to biomass in other related studies.

However, in this case the non-linear transformation only improved the correlation of from R^2 = 0.94 to 0.96.

Equation 1. Non-linear Height and Reflectance Index (NHRI)

$$NHRI = ln(Height_{Lidar}) * NDVI_{ACS470}$$

Conclusion

This preliminary study has demonstrated that the relatively cheap Lidar sensor can be correlated to TDM with at least a similar degree of accuracy as the traditional plate meter. Although the AOS tested in this study reported better correlation than the Lidar, the integration of the two provided the highest accuracy. Further exploration of the Lidar data is warranted as this study only examined the mean height of linear scans, which is only one of many metrics that might be derived from the Lidar data. More complex metrics could explore the density of the sward at various heights which may provide a better correlation with biomass. Although this study integrated two different devices to develop the Non-linear Height and Reflectance Index future research should focus on the engineering of low cost dual band Lidar sensors from which height by reflectance might be derived from a single device.

Acknowledgements

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References

Henry, D, Shovelton, J, de Fegely, C, Manning, R, Beattie, L, Trotter, M (2013) Potential for information technologies to improve decision making for the southern livestock industries. Meat & Livestock Australia Ltd, North Sydney NSW

Moges, SM, Raun, WR, Mullen, RW, Freeman, KW, Kohnson, GV, Solie, JB (2004) Evaluation of green, red and near infrared bands for predicting winter wheat biomass, nitrogen uptake, and final grain yield. *Journal of Plant Nutrition* 27, 1431-1441.

Radtke, PJ, Boland, HT, Scaglia, G (2010) An evaluation of overhead laser scanning to estimate herbage removals in pasture quadrats. *Agricultural and Forest Meteorology* 150, 1523-1528.

Schaaf, C, Paynter, I, Saenz, E, Li, Z, Strahler, A, Peri, F, Erb, A, Raumonen, P, Muir, J, Howe, G (2014) Using the Rapid-Scanning, Ultra-Portable, Canopy Biomass Lidar (CBL) Alone and In Tandem with the Full-Waveform Dual-Wavelength Echidna® Lidar (DWEL) to Establish Forest Structure and Biomass Estimates in a Variety of Ecosystems. *AGU Fall Meeting Abstracts* 1, 01.

Schaefer, MT, Lamb, DW (2016) A Combination of Plant NDVI and LiDAR Measurements Improve the Estimation of Pasture Biomass in Tall Fescue (Festuca arundinacea var. Fletcher). *Remote Sensing* 8, 109.

Smith, RCG, Adams, M, Gittins, S, Gherardi, S, Wood, D, Maier, S, Stovold, R, Donald, G, Khohkar, S, Allen, A (2011) Near real-time Feed On Offer (FOO) from MODIS for early season grazing management of Mediterranean annual pastures. *International Journal of Remote Sensing* 32, 4445-4460.

Trotter, M (2013) PA Innovations in livestock, grazing systems and rangeland management to improve landscape productivity and sustainability. *Agricultural Science* 25, 27-31.

Trotter, MG, Lamb, DW, Donald, GE, Schneider, DA (2010) Evaluating an active optical sensor for quantifying and mapping green herbage mass and growth in a perennial grass pasture. *Crop and Pasture Science* 61, 389-398.

Trotter, MG, Schneider, D, Lamb, D, Edwards, C, McPhee, M (2012) Examining the potential for active optical sensors to provide biomass estimation in improved and native pastures. In 'Australian Agronomy Conference. Armdiale, Australia'. (The Regional Institute: Gosford)

Yule, IJ, Lawrence, H, Murray, R (2010) Pasture yield measurement with the C-dax Pasturmeter. In 'International COnference on Precision Agriculture. Denver Colorado'. (Ed. R Khosla)