PROXIMAL SENSING TOOLS TO ESTIMATE PASTURE QUALITY PARAMETERS

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ABSTRACT

To date systems for estimating pasture quality have relied on destructive sampling with measurement completed in a laboratory which was very slow, time consuming and expensive. Results were often not received until after the pasture was grazed which defeated the point of the measurement, as farmers required the information to make decisions about grazing strategies to use pasture effectively and provide high quality feed for milk or meat production. The objective of this in-field approach is to produce measurement results in near real time. These methods were tested using a range of proximal sensors and statistical methodologies.

The following range of pasture quality parameters have been considered; crude protein (CP), acid detergent fibre (ADF), neutral detergent fibre (NDF), ash, dietary cation-anion difference (DCAD), lignin, lipid, metabolisable energy (ME) and organic matter digestibility (OMD).

The sensing methodologies used include, a hyperspectral sensor (ASD FieldSpec® Pro FR), a multispectral Cropscan™ 16 channel passive sensor as well as two and three channel active sensors, Greenseeker™ and Crop Circle ACS - 470™.

Results indicate that it is possible to achieve high rates of explanation of nutritive values within pasture. The effects of seasonal variation were also measured. A summary of the results achieved for the various approaches is given.

Keywords: Hyperspectral radiometry, multispectral sensors, pasture nutritive value, pasture quality.

INTRODUCTION

New Zealand's highly productive pastoral agriculture sector is based on ruminants grazing year-round on pasture due to favourable growing conditions in the prevailing temperate climate. High pasture utilisation is essential to high performance grazing systems and total pasture production and quality is a performance indicator for business profitability (Pullanagari et al., 2012c). This is often achieved through pasture budgeting techniques. Although sophisticated software based feed budgeting systems exist, they suffer from the lack of accurate, comprehensive and repeatable pasture measurements supplying data to the system. This remains difficult because there remain no practical means to measure pasture production on a sufficiently large scale. In some cases simple visual assessment is used but this suffers from lack of accuracy between seasons and over the longer term. Some pedestrian systems exist such as the plate meter but these were unsatisfactory for a number of reasons including: low sample numbers leading to potential error, lack of consistency between operators, time consuming operation and manual data entry to feed budgeting systems. In New Zealand, the C-Dax Pasturemeter which is towed behind an ATV or RTV has been accepted by increasing numbers of farmers to carry out their pasture measurement. This has led to an increase in the number of farmers actively feed budgeting and in most cases increases in productivity have been achieved through better feed utilisation and increased growth.

Rapid and repeatable measurement of pasture mass is a step forward, however, tools for measuring pasture quality are not yet available. Pasture quality is important to maximise the intake of grazing dairy cows, and must be maintained throughout the season, even when perennial plants would normally become reproductive and when irrigation is used. Recently, interest in pasture quality has increased due to its importance in achieving high intakes in individual cows and higher costs involved in diet supplementation for additional milk production. Future needs to understand specific nutrients for example crude protein are likely as approaches to managing the environmental footprint of farming evolve. The current methods used to measure pasture quality are time consuming, expensive and slow. They include destructive sampling with samples being removed to an analysis laboratory and results taking several weeks to be produced using wet chemistry. Laboratory based VIS/NIR instruments are also being used, but still rely on destructive sampling and transport delays. Alternatively, proximal sensors have the potential to predict in-situ pasture quality rapidly and non-destructively. In this regard, researchers (Biewer et al., 2009; Kawamura et al., 2009; Pullanagari et al., 2012a; Starks et al., 2006) have attempted to establish relationships between sensor data and measured pasture quality data. This paper explains the potential ability of selected sensors to estimate pasture quality using data from samples of mixed sward obtained from commercial dairy farm pasture in a number of locations in New Zealand.

MATERIAL AND METHODS

Three proximal sensors, ASD FieldSpec® Pro FR (hyperspectral), Cropscan™ (multispectral) and Crop Circle™ Model ACS-470 (multispectral), were tested for their ability to predict pasture quality. The study was conducted on commercial dairy farms across New Zealand in order to represent wide range of environmental conditions and pasture quality parameters. The pastures mainly comprised of rye grass (*Lolium perenne* L.) and clover (*Trifolium repens* L.) with a small proportion of weeds. The number of cut pasture samples used in the analytical data set to develop the calibration models were n = 107 for hyperspectral sensor study, n=70 for Cropscan study and n= 200 for Crop Circle study. In each case samples were analysed using the proximal sensors, using consistent sampling methodology between the sample plots. Samples were then cut and removed following the in-situ measurement and presented for laboratory analysis. In order to assess season-specific predictions of pasture nutritive value from the multispectral instrument a further 420 samples were used on four sites in different locations within New Zealand over three seasons (autumn, spring and summer) in 2009 - 2010.

Hyperspectral readings were taken, using ASD FieldSpec® Pro FR equipped with a canopy pasture probe (CAPP)-top grip coupled with 50 Watts tungsten-quartz-halogen bulb (Sanches et al., 2009) which ensures consistent illumination and stable measurement conditions, on selected pasture plots. The spectral range of the instrument is 350-2500 nm with 1 nm spectral resolution. After acquiring the spectra, data processing and statistical analysis were employed. Under the data processing procedure, the hyperspectral data was log transformed, smoothed and converted into first derivative transformation. Then a partial least square regression (PLSR) statistical procedure was applied to establish relationships between measured and predicted values. A full description of this is given in Pullanagari et al (2012).

A Cropscan multispectral sensor was used for scanning pasture samples. This sensor records the spectral reflectance in 16 discrete wavelengths (460, 480, 530, 620, 670, 700, 740, 770, 800, 930, 970, 1080, 1200, 1300, 1580 and 1680 nm) with a spectral resolution of 7-16 nm of the electromagnetic spectrum. Reflectance measurements were collected between 10 am and 4 pm to capture optimal natural lighting conditions. For this reason this sensor is termed a "passive sensor".

In addition to above sensors, a Crop Circle ACS-470 sensor was used. This sensor has its own light source hence it can be called an active sensor. It acquires the spectral reflectance in 3 different discrete wavelengths (670, 730 and 760 nm) of the electromagnetic spectrum. The captured spectral reflectance values were transformed into the vegetation index, pasture index (PI), then correlated with measured values. The specifications of the sensors used are illustrated in Table 1.

Table 1 Sensor specifications for hyper and multispectral sensors (Pullanagari et al., 2011)

S.No	Specification	Hyper Spectral Sensor	Multi Spectral Sensor	
1	Name	ASD Field Spec® Pro	CROPSCAN ™	Crop Circle™
2	Sensor type	Passive	Passive	Active
3	Spectral range	350-2500	440-1680	450-880
4	Spectral Bands	2150	16	3
5	Spectral Resolution	1-2 nm	7-16 nm	10-20
6	Detectors	Silicon (300-1000 nm) TE cooled, InGaAs (1000-2500 nm)	Silicon and Germanium	Silicon
7	Foot print	20 cm dia.	60 x 60 cm	5×60 cm
8	FOV	8°,18°,25°	28°	32°/6°
9	Distance from target	1 m	1.2 m	0.6-1.2 m

The corresponding samples of spectral reflectance were harvested and returned to the laboratory for drying at 70^{o}C for 24 h and ground to pass a 1 mm sieve. The quality parameters were quantified using lab near-infrared reflectance spectroscopy at FeedTECH laboratory (AgResearch Palmerston North, New Zealand). The pasture quality parameters considered include; Crude protein (CP), acid detergent fibre (ADF), neutral detergent fibre (NDF), ash, dietary cation-anion difference (DCAD), lignin, lipid, metabolisable energy (ME) and organic matter digestibility (OMD). Further paired validation data sets were used, using similar numbers of samples.

RESULTS AND DISCUSSION

Partial least squares regression (PLSR) was applied to hyperspectral data in order to establish relationships between laboratory estimated values and the values predicted from calibration equations. Quality parameters including CP, ADF, NDF, DCAD, lignin, ME and OMD were significantly predicted with high accuracy using in-situ testing with hyperspectral techniques.

Table 2 The results of the hyperspectral sensor (Pullanagari et al., 2012a)

Pasture quality parameters	r^2	RMSE
CP	0.82	2.08
ADF	0.81	2.13
NDF	0.77	4.22
Ash	0.65	0.74
DCAD	0.77	55.92
Lignin	0.71	0.41
Lipid	0.56	0.47
ME	0.83	0.46
OMD	0.83	4.13

After acquiring the reflectance values at 16 wavelengths of the Cropscan sensor, the values were interpreted into stepwise multiple linear regression (SMLR) to regress against the laboratory estimated values. The results of the regression models are presented in Table 3. Most quality parameters were predicted with moderate accuracy whilst ADF, NDF and lignin were predicted with low accuracy compared to the hyperspectral sensor results (Table 2), the results were achieved with moderate accuracy. Although 16 wavelengths are available in this instrument it is likely that a reduced number of measurement wavelengths could be utilised to produce acceptable results over a range pasture quality parameters. In addition, the variation in the results may in part be due to the differences in range of quality parameter values in the datasets used in the model development process.

Table 3 The results of multispectral sensor (Cropscan™) (Pullanagari *et al*., 2012b)

Pasture quality parameters	r^2	RMSE
CP	0.72	2.82
ADF	0.59	2.69
NDF	0.45	5.33
Ash	0.67	0.80
DCAD	0.80	62.25
Lignin	0.52	0.51
Lipid	0.71	0.67
ME	0.72	0.53
OMD	0.76	4.57

In contrast to the above sensors, the Crop Circle sensor was unable to meaningfully predict any of the pasture quality parameters. However, it did demonstrate the potential to predict standing crude protein (Figure 1) which is a function of crude protein concentration and pasture biomass.

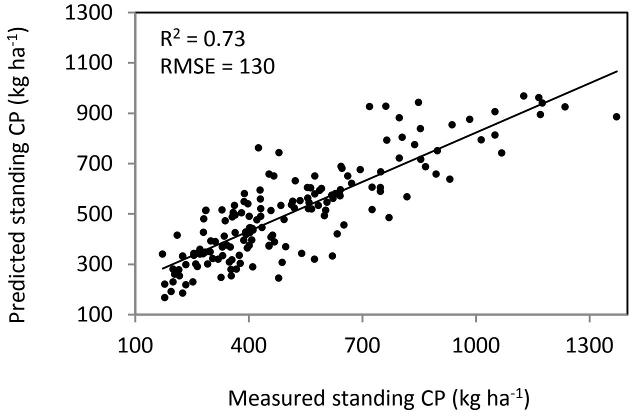

Figure 1 Relationship between measured and predicted standing crude protein (Pullanagari, 2012)

Table 4 Results of seasonally based analysis using the multispectral sensor (Cropscan™) and PLSR. Based on data from (Pullanagari *et al* 2012c).

	Autumn season (n=235)		**Spring Season (n=85)**		**Summer Season (n=100)**	
Pasture quality parameters	r^2	RMSE	r^2	RMSE	r^2	RMSE
CP	0.80	2.05	0.80	1.83	0.86	1.84
ADF	0.80	2.15	0.55	1.08	0.60	1.51
NDF	0.80	4.09	0.65	1.73	0.5	3.49
Ash	0.44	0.90	0.87	0.44	0.84	0.61
Lignin	0.76	0.37	-	-	--	-
Lipid	0.63	0.49	0.30	0.35	0.52	0.37
ME	0.84	0.49	0.50	0.27	0.50	0.44
OMD	0.85	4.21	0.40	2.47	0.51	3.05

Table 4 illustrates the results of seasonally based models using PLSR. A full analysis of these results are presented in Pullanagari et al (2012c), where a number of reasons for the variability of the seasonal results is offered. It is thought these empirical models are sensitive to canopy structure and the proportions of photosynthetically active and non-active vegetation. In some cases reduced variation and sample number also contribute to the lower levels of explanation offered for some seasons.

The above tools demonstrate the potential to assist dairy farmers to obtain qualitative information on their pastures that can be useful to adopt precision management practices and dispense with the requirement for destructive testing. However, more work is required in terms of developing fully calibrated robust models to characterise pasture nutritive value which could be used reliably on a day to day basis with inexpensive equipment to give farmers information on their pasture quality.

CONCLUSIONS

Proximal sensors proved capable of predicting in-situ pasture quality non-invasively on commercial dairy pastures in New Zealand. The information on pasture quality from the sensors allow dairy farmers to optimise decision making such as adjusting the stocking rate to utilise pasture efficiently and providing good quality pasture for the maximum duration. This is true whether pasture is the only source of food for the cows or pasture is used to provide the baseline diet for higher producing cows in grain supplemented systems. Having a readily available method of pasture quality measurement may also lead to a better understanding of the mechanisms influencing that pasture quality and the extent to which it varies throughout a season. This will give farmers a more informed approach to management interventions.

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