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Proximal sensing techniques to monitor pasture quality and quantity on dairy farms

A thesis presented in partial fulfilment of the requirements for the degree of

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in

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New Zealand

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Abstract

Regular and timely measurements of pasture quality and quantity allow dairy farmers to make effective decisions ensuring an adequate supply of nutrients to animals, efficient utilization of pasture, manipulation of stocking rates, management grazing intervals, and optimisation of input resources (e.g. nitrogen fertilisers) which results in more economic, environmentally aware, sustainable grazing systems.

The objectives of this research were to investigate the potential of proximal sensing tools to estimate pasture quality parameters (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) in mixed pastures. Three proximal sensors, ASD FieldSpec® Pro FR spectroradiometer (hyperspectral), Cropscan™ (multispectral) and Crop Circle™ (multispectral), were employed in this study.

In the hyperspectral study, the spectral reflectance measurements of pasture samples were acquired using an ASD FieldSpec® Pro FR spectroradiometer which has a spectral range of 350-2500 nm and attached with canopy pasture probe (CAPP) to ensure ambient light conditions. The acquired spectral data were pre-processed by various procedures: spectral averaging, smoothing and derivative transformation, then partial least squares regression was applied to regress against the corresponding measured values. The regression model was validated with an external dataset to evaluate the reliability and robustness of the model. The performance of both calibration and validation models were more or less similar. The validation model predicted the pasture quality parameters CP, ADF, NDF, ash, DCAD, lignin, ME and OMD with reasonable accuracy (0.65 ≤ R² ≤ 0.83; 1.70 ≤ RPD ≤ 2.48; 0.64 ≤ NSE ≤ 0.83) and the lipid was predicted with lower accuracy (R²-0.55; RPD-1.44; NSE-0.50).

Cropscan relies on sunlight for its energy source and measures reflectance in 16 broad wavebands; it was evaluated for its potential to assess pasture quality parameters that are collected in one season. The relationship between spectral reflectance measured using the Cropscan and pasture quality parameters were established using single wavebands, new vegetation indices and stepwise multiple linear regression (SMLR) and the models were
validated with an external dataset. Of all the models, the new non-linear new combination of RDVI index models were performed satisfactory results ($0.65 \leq R^2 \leq 0.85$) for predicting CP, DCAD, ME and OMD. CP, ash, DCAD, lipid, ME and OMD were estimated with moderate accuracy ($0.60 \leq R^2 \leq 0.80$) using the SMLR model. The Cropscan instrument was also used to test the potential for predicting pasture quality in different seasons (autumn, spring and summer). Improved accuracy was observed with season-specific models as compared to the combined season dataset models.

A three channel active optical sensor, Crop Circle™ was used to estimate herbage biomass and standing crude protein (SCP) using various indices. The results showed that the three channel based pasture index proved a reliable index for estimating biomass ($R^2 = 0.69$; RMSE = 518 kg ha$^{-1}$) and SCP ($R^2 = 0.77$; RMSE = 110 kg ha$^{-1}$) with moderate accuracy. Based on the calibration of PI, spatial analysis was assessed for biomass in ten dairy fields. In spatial analysis, semivariograms revealed the spatial dependency for biomass was moderate to strong and varied between the fields.

This study indicates that proximal sensors have considerable potential for real-time in situ assessment of pasture quality and quantity in mixed pastures. The results indicate that spectral resolution and number of wavelengths used in the sensor are crucial for determining pasture quality with high accuracy which would allow future research to develop proximal sensors with an optimal number of wavelengths and spectral resolution.
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## Acronyms

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<tr>
<th>Acronym</th>
<th>Full Form</th>
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<tbody>
<tr>
<td>AI</td>
<td>artificial intelligence</td>
</tr>
<tr>
<td>ANN</td>
<td>artificial neural networks</td>
</tr>
<tr>
<td>AOAC</td>
<td>association of official analytical chemists</td>
</tr>
<tr>
<td>ASD</td>
<td>analytical spectral devices – ASD Inc.</td>
</tr>
<tr>
<td>ADF</td>
<td>acid detergent fibre</td>
</tr>
<tr>
<td>AVIRIS</td>
<td>airborne visible infrared imaging spectrometer</td>
</tr>
<tr>
<td>CAPP</td>
<td>canopy pasture probe</td>
</tr>
<tr>
<td>CCRS</td>
<td>canada centre for remote sensing</td>
</tr>
<tr>
<td>CV</td>
<td>coefficient of variation</td>
</tr>
<tr>
<td>DCAD</td>
<td>dietary cation-anion difference</td>
</tr>
<tr>
<td>DM</td>
<td>dry matter</td>
</tr>
<tr>
<td>EM</td>
<td>electromagnetic</td>
</tr>
<tr>
<td>FDR</td>
<td>first derivative reflectance</td>
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<tr>
<td>FOV</td>
<td>field of view</td>
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<tr>
<td>GIS</td>
<td>geographic information system</td>
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<tr>
<td>GPS</td>
<td>global positioning system</td>
</tr>
<tr>
<td>IR</td>
<td>infrared</td>
</tr>
<tr>
<td>LAI</td>
<td>leaf area index</td>
</tr>
<tr>
<td>LIBERTY</td>
<td>leaf incorporating biochemistry exhibiting reflectance and transmittance yields</td>
</tr>
<tr>
<td>LV</td>
<td>latent variable</td>
</tr>
<tr>
<td>ME</td>
<td>metabolisable energy</td>
</tr>
<tr>
<td>MIR</td>
<td>mid infrared</td>
</tr>
<tr>
<td>NASA</td>
<td>national aeronautics and space administration</td>
</tr>
<tr>
<td>NDF</td>
<td>neutral detergent fibre</td>
</tr>
<tr>
<td>NDVI</td>
<td>normalised difference vegetation index</td>
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<tr>
<td>NIR</td>
<td>near infrared region</td>
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<tr>
<td>NSE</td>
<td>nash-sutcliffe efficiency</td>
</tr>
<tr>
<td>NV</td>
<td>nutritive value</td>
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NIRS  near infrared reflectance spectroscopy
OMD  organic matter digestibility
PCA  principal component analysis
PCR  principle component regression
PLSR  partial least squares regression
PRESS  predicted residual error sum of square
$R^2$  coefficient of determination
RDVI  renormalized difference vegetation index
REP  red edge position
RMSE  root mean square error
RMSECV  root mean square error of cross-validation
RMSEP  root mean square error of prediction
RPD  ratio prediction to deviation
SD  standard deviation
SAIL  scattering by arbitrarily inclined leaves
SAR  synthetic aperture radar
SAVI  soil adjusted vegetation index
SMLR  stepwise multiple linear regression
SWIR  shortwave infrared
SVM  support vector machines
SVR  support vector regression
USDA  united states department of agriculture
UV  ultra violet
VI  vegetation indices
VIP  variable importance for the projection
Vis/VIS  visible
Vis-NIRS  visible near infrared spectroscopy