Computers and Electronics in Agriculture 123 (2016) 256–263

Contents lists available at ScienceDirect

Computers and Electronics in Agriculture

journal homepage: www.elsevier.com/locate/compag

Original papers

Determination of fibre and protein content in heterogeneous pastures using field spectroscopy and ultrasonic sward height measurements

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ARTICLE INFO

Article history:
Received 5 October 2015
Received in revised form 1 March 2016
Accepted 3 March 2016
Available online 14 March 2016

Keywords:
Forage quality
Proximal remote sensing
Ultrasonic sensor
Field spectroscopy
Sensor combination

ABSTRACT

Feeding of livestock on pastures requires constant monitoring of diet composition to ensure consistent levels of animal production. The widely used but conventional techniques to measure the components of feed are impractical to obtain in-field forage quality status for making real-time decisions. Assessment of forage quality parameters using proximal sensing is of particular interest. The present study aimed to demonstrate the potential of using a combination of ultrasonic and canopy reflectance data to predict forage quality variables of heterogeneous pastures. A field experiment with pastures continuously grazed by cows with three stocking density treatments (moderate, lenient and very lenient stocking) was used to calibrate ultrasonic and hyperspectral reflectance sensors. Hyperspectral analysis by a modified partial least square regression (MPLSR) resulted in maximum accuracy for the prediction of acid detergent fibre (ADF) and crude protein (CP) ($R^2_{\text{calibration}}$ = 0.63–0.85). Any reduction of hyperspectral data into vegetation indices based on few specific narrow wavebands or satellite broadbands reduced prediction accuracy significantly. However, prediction of ADF and CP was improved by a combined analysis of ultrasonic sward height and vegetation indices or satellite broadbands, so that most calibration models exceeded an RPD (ratio of standard deviation and standard error of prediction) value of 1.4, which is considered as an acceptable predicting capability for variable field condition. Our findings showed that combined sensing systems using reflectance and ultrasonic sensors may provide acceptable prediction accuracies for practical application even under extremely heterogeneous pasture conditions.

1. Introduction

Feeding of livestock on pastures requires constant monitoring of diet composition to ensure consistent levels of animal production (Deaville and Flinn, 2000). Pasture quality is highly variable within and between paddocks and during the growing season due to differences in species composition, sward maturity, soil type and topography as well as climatic factors (Pullanagari et al., 2012). Management decisions such as grazing intensity can also influence pasture quality (Pavlů et al., 2006). The widely used but conventional techniques of wet chemistry and laboratory based VIS/NIR techniques to measure the components of feed quality are expensive, destructive, and labour and time consuming (Zhao et al., 2007). Moreover, these methods are impractical to determine the in-field forage quality status for making real-time decisions. Ground based (proximal) remote sensing technologies have been recognized as practical means to estimate various biophysical and biochemical properties of vegetation at the field scale (Starks et al., 2006). Assessment of forage quality parameters using proximal sensing of pasture canopy reflectance is of particular interest. While broadband multispectral sensors are considered to have limitations in providing accurate estimates of vegetation characteristics (Thenkabail, 2012), hyperspectral sensors with narrow and near-continuous spectra allow much more detailed spectral information and offer significant improvements over broadband sensors. Partial least square regression (PLSR) is a technique for analysing spectral datasets that employs the whole range of hyperspectral data in the analysis. Several studies have shown that PLSR is a powerful tool to accurately predict forage quality constituents under field conditions (Biewer et al., 2009; Starks et al., 2004; Li et al., 2014a). However, due to costs and complexity of hyperspectral data, reducing the spectral data range and identification of the best spectral features of hyperspectral information would facilitate simple sensor applications in the field (Biewer et al., 2009; Li et al., 2014b; Reddersen et al., 2014). One option is the selection of

Abbreviations: ADF, acid detergent fibre; CP, crude protein; DM, dry matter; MPLSR, modified least square regression; PLSR, partial least square regression; RPD, ratio of standard deviation and standard error of prediction; SLU, standard livestock units; USH, ultrasonic sward height.

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http://dx.doi.org/10.1016/j.compag.2016.03.002
0168-1699/

optimal wavebands that provide the best information by developing two-wavelength reflectance ratios from hyperspectral data. Comparisons between traditional vegetation indices (VIs) (which commonly use average spectral information over predetermined broad-band wavelengths) and hyperspectral narrowband VIs showed a lower accuracy of traditional VIs than for narrowband VIs derived from hyperspectral measurements for various vegetation characteristics (Thenkabail et al., 2000; Mutanga and Skidmore, 2004; Inoue et al., 2008; Fricke and Wachendorf, 2013). VIs based on visible and NIR reflectance indicate saturation at high biomass values which limit their sensitivity to further changes in biomass accumulation (Cammarano et al., 2014). As selection of specific narrow wavelengths or reducing the hyperspectral range may lead to a loss of spectral information, combining spectral data with information from other sensors may be effective. Sward height measured by ultrasonic distance sensor (referred as ultrasonic sward height (USH)) may provide useful information, as forage quality is known to be negatively correlated with the growth height of the plants (Hofmann et al., 2001; Pavlů et al., 2006; Summers and Putnam, 2008). The combination of ultrasonic and spectral sensors has been previously utilized for the prediction of biomass in sown grasslands with acceptable accuracies (Fricke and Wachendorf, 2013; Reddersen et al., 2014; Pittman et al., 2015). However, the benefit of such a combined sensing technique for a non-destructive determination of forage quality in heterogeneous pastures has yet to be verified.

In order to reduce hyperspectral information to few variables we tested several approaches, such as normalized difference spectral indices (NDSIs) using narrowband reflectance combination (according to the normalized difference vegetation index (NDVI) type formula), multi-spectral satellite bands (according to 8 broadbands of WorldView-2 satellite) and principle component analysis (PCA) derived components. Thus, the goal of this study was to test the performance of those spectral variables derived from hyperspectral data exclusively and in combination with USH and compare it to modified partial least square regression (MPLSR) models for predicting crude protein (CP) and acid detergent fibre (ADF) of heterogeneous pastures, which were continuously stocked by cows with differing stocking density.

2. Materials and methods

2.1. Study area and site characteristics

The research was conducted on a heterogeneous permanent pasture at the experimental farm Relliehausen of the University of Goettingen in the Solling uplands, Lower Saxony (51°46′55″N, 9°42′13″E, 180–230 m above mean sea level). The site has been described in detail by Wrage et al. (2012). Briefly, the soil was characterized as pelosol-brown with pH of 6.3. Average annual rainfall was 879 mm with an average temperature of 8.2 °C. The grassland was a moderately species-rich *Lolio-Cynosuretum*. The one hectare paddocks were continuously stocked by Simmental cows with three stocking density treatments as follow: (a) moderate stocking, average of 3.4 standard livestock units (SLU, i.e. 500 kg live weight) per hectare, (b) lenient stocking, average of 1.8 SLU per hectare, (c) very lenient stocking, average of 1.3 SLU per hectare. Treatments were replicated 3 times and the grazing season lasted from May to October, usually interrupted by breaks in July or August due to insufficient sward productivity.

2.2. Field measurements and plant sampling

Field measurements were carried out within one paddock of each stocking density at three sampling dates in 2013 ((i) 3rd to 5th June, (ii) 21st to 23rd August and (iii) 30th September to 2nd October) and 2014 ((i) 20th to 22nd May, (ii) 15th to 17th July and (iii) 23rd to 30th September). For sensor measurements and plant sampling subplots with the area of 0.25 m^2 were selected and marked in each paddock representing the range of sward compositions and structures. A Trimble GPS device with ASCOS reference data correction (mean horizontal accuracy = 10 cm) was used to avoid repeated subplot locations during two year measurements. Canopy hyperspectral reflectance was acquired at each sampling location using a hand-held spectroradiometer (Portable HandySpec Field VIS/NIR, Tec-5 AG, Germany) in the range from 305 to 1700 nm (Fig. 1) with 1 nm reading intervals and a field of view (FOV) of 25°. The spectrometer head was held approximately 1 m above the canopy. A gray Spectralon reference panel was used at fixed intervals to calibrate the spectral measurements.

An ultrasonic distance sensor of type UC 2000-30GM-IUR2-V15 (Pepperl and Fuchs, Mannheim, Germany) was used to gather USH measurements. The beam angel of the device was about 25° and the sensing distance ranged from 0.8 to 200 cm (Pepperl and Fuchs, 2010). The ultrasonic echo was converted into an output voltage linear to the measured distance and subsequently transformed by an A/D converter into numerical values, logged on a personal computer and finally converted into sward height values using the linear regression Eq. (1).

$$y = a - 159.03 + 0.08756x \quad (1)$$

where a = mount height of the ultrasonic sensor above soil surface (cm), x = values from AD/converter (proportional to distance related voltage output), and y = ultrasonic sward height (cm).

At each subplot, five measurements were recorded with the ultrasonic sensors placed at five positions on a frame at a height of about 1 m. The estimated USH for the subplot was calculated as the average value of the five measurements. A detail description of USH device and methodology can be found in Fricke et al. (2011). After sensor measurements were made in each sampling location, all vegetation in the 0.25 m^2 area was clipped at ground surface level. For botanical analysis, a subsample of herbage was separated into fractions of grasses, legumes, herbs, mosses and dead material and dried at 105 °C for 48 h to determine the dry matter (DM) proportion of each functional group.

2.3. Assessment of forage quality data

Approximately 100–500 g of sample fresh matter was dried at 65 °C for 72 h and were ground with a 1-mm sieve. Subsequently,

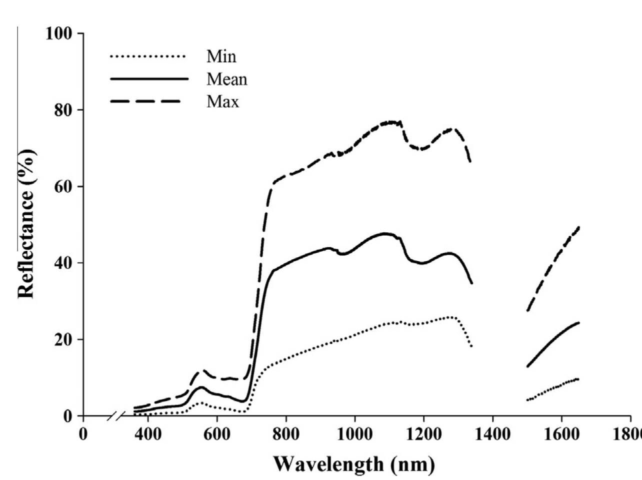

Fig. 1. Canopy hyperspectral mean, minimum and maximum reflectance derived from each 1 nm wavelength calculated for all samples (common swards, N = 323).