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Evaluation of models for assessing *Medicago sativa* L. hay quality

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Abstract

A study was conducted to evaluate current proposed models for assessing *Medicago sativa* L. hay quality, using near infrared reflectance spectroscopy (NIRS) analyses and Cornell Nett Carbohydrate and Protein System (CNCPS) milk production prediction as a criterion of accuracy. Application of the theoretically-based summative total digestible nutrients (TDNlig) model of Weiss *et al*. (1992), using lignin to determine truly digestible NDF, explained almost all of the variation in milk yield (MY) ($r^2 = 0.98$). However, this model involves high analysis costs to develop and maintain NIRS calibrations and several of its components were poorly predicted by NIRS and therefore, not suited for quality assessment in practice. Current available models (forage quality index (FQI), relative forage quality (RFQ); relative feed value (RFV)) for assessing *Medicago sativa* L. hay quality revealed lower accuracies ($r^2 = 0.83$, $r^2 = 0.76$, $r^2 = 0.61$, respectively), especially when protein was included in the model (total forage quality index (TFI); $r^2 < 0.49$). The developed empirical equation named lucerne milk value (LMV), including ADF, ash and lignin (Y = b0 – b1ADF – b2ash – b3lignin) ($r^2 = 0.96$), proved to be the most practical, simplistic, economical and accurate quality evaluation model for commercial application.

Keywords: Lucerne hay, CNCPS, NIRS, FQI, LMV, RFQ, RFV, TFI
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Introduction

Several quality evaluation models have been developed over the history of forage quality evaluation research (Moore & Undersander, 2002) namely; Relative Feed Value (RFV; Rohweder *et al*., 1976), Total Forage Index (TFI; Hutjens, 1995), Adjusted Total Forage Index (ATFI; Erasmus, 2000), Forage Quality Index (FQI; Moore & Undersander, 2002), Relative Forage Quality (RFQ; Moore & Undersander, 2002). The fundamental characteristic of diets for ruminants, around which all other nutrients are structured, is energy content (Van Soest, 1994). Therefore, the majority of existing models for lucerne hay quality assessment are based on its digestible energy intake potential. Some models also include protein parameters. According to Scholtz (2008) protein parameters are, however, an unreliable indicator of lucerne hay quality.

It is important to consider the animal to evaluate the different available models for assessing lucerne hay quality (Scholtz, 2008). In this regard the Cornell Net Carbohydrate and Protein System (CNCPS), as proposed by Tylutki *et al*. (2008), could be an important and valuable tool to evaluate the accuracy of different models to determine the quality of lucerne hay for milk production. Accordingly, the usage of near infrared reflectance spectroscopy (NIRS) is essential for the rapid analysis of lucerne hay and should the accuracy of calibration equations be considered when selecting the appropriate model for lucerne hay quality grading.

The objective of this study was to evaluate current proposed models for assessing lucerne hay quality, using NIRS analyses and CNCPS milk production prediction as a criterion of accuracy.

Materials and Methods

Six hundred lucerne (*Medicago sativa* L.) hay samples were collected from several commercial irrigation farms in the main lucerne producing areas in South Africa, as described by Scholtz, (2008). Hundred and sixty eight samples that represented the South African lucerne hay population were selected, analysed (chemical and *in vitro*) and near infrared reflectance spectroscopy (NIRS) calibration equations developed (Scholtz *et al*., 2009b).

The following models were used to estimate lucerne hay quality

a) Relative feed value (RFV) = (%DDM) × (DMI as % of body weight) × (0.775) (Rhoweder *et al*., 1976)
b) Forage quality intake (FQI) = TDN intake, g/M $^{0.75}$ /29 (Moore & Undersander, 2002)
c) Total forage index (TFI) = RFV + %CP x 6 (Hutjens, 1995)
d) Adjusted total forage index (ATFI) = RFV + adjusted CP (ACP) x 6 (Erasmus, 2000)
e) Relative Forage Quality (RFQ) = DMI % of BW) x (TDN % of DM) / 1.23 (Moore & Undersander, 2002)
f) Total digestible nutrients (TDN1X) = tdCP + (tdFA x 2.25) + tdNDF + tdNFC – 7n (Weiss *et al*., 1992)

A modified version of CNCPS (CNCPSv6) (AMTS.Cattle version 1.1.0.1, AMTS, LLC, 418 Davis RD, Cortland, NY, 13045, USA) was used to calculate the effect of lucerne hay quality on metabilisable energy (ME) and metabolisable protein (MP) allowable milk, as described by Scholtz, (2008). The lowest ME or MP allowable milk, known as milk yield (MY), for each lucerne hay was used as an evaluation criterion for the different quality models.

Statistical analyses were performed using SAS 9.1.3 Service Pack 4 (2002-2003).

Results and Discussion

From the results in Table 1 it is evident that the highest correlation of a quality model with MY was obtained with the summative TDN equation of Weiss *et al*. (1992), using lignin to determine truly digestible NDF (NDFDlig). The NRC (2001), however, recommended the use of either neutral detergent fibre digestibility at 48 hours (NDFD48) or NDFDlig to determine truly digestible NDF. The large difference obtained in the accuracy of predicting MY from TDN using NDFDlig (TDNlig; $r^2 = 0.96$) and TDN using NDFD48 (TDN48; $r^2 = 0.74$), respectively in the current study, are in disagreement with the above recommendations of the NRC (2001). Although highly significant ($P < 0.0001$), the relationship ($r^2 = 0.2$) between NDFDlig and NDFD48 was not good enough to be used interchangeably for the estimation of the summative TDN equation. Similar results were obtained by Robinson *et al*. (2004) who also evaluated the NRC (2001) lignin model (NDFDlig) to estimate NDFD. They found little relationship between NDFD as estimated by lignin (NDFDlig) and *in vitro* NDFD at 48 hours (NDFD48) in barley and distillers grain. They reported a superior relationship using the *in vitro* digestibility (NDFD48) measurements as comparing to using lignin (NDFDlig) to estimate NDFD. Robinson *et al*. (2004) stated that "the primary reason for this occurrence was the absolute failure of the lignin-based procedure to predict in vitro digestion of NDF at 48 hours. In addition, Linn (2003) suggested that the NDFDlig equation does not consider feed type. Lignin does affect digestibility of NDF, however, the effect is variable with different forages, cuttings and/or environments. Consequently, a universal NDFD equation for all types of forages is highly unlikely. Hoffman *et al*. (2003) suggested that the influence of NDFD on total TDN prediction of forages is reasonably small in relationship to all the factors that influence energy status in ruminant animals. However, in the current study the replacement of NDFD48 with NDFDlig in the TDN equation, explained 24% more of the variance in MY.

Even though NDFDlig had a dramatic impact on the ability of TDNlig to predict MY, a relative poor negative but significant ($P < 0.0001$) correlation was reported by Scholtz, (2008) between lignin and MY ($r = -0.62$) for South African lucerne hay. Similar low correlations were also found between these two (TDNlig and MY) and IVOMD48 ($r = 0.58$ and $r = 0.60$, respectively; $P < 0.0001$). Analysis of correlation between TDNlig and NFC ($r = 0.91$), ADF ($r = -0.81$) and NDF ($r = -0.76$) showed strong to moderate significant ($P < 0.0001$) relationships. NFC showed the highest ($r = 0.91$), whereas CP the lowest ($r = 0.19$) correlation with TDNlig (Table 2). This was expected due to the high and low contribution of NFC and CP, respectively to the TDNlig equation.

The almost perfect relationship ($r = 0.98$; Table 1) between TDNlig of lucerne hay and MY, predicted from the complete diet seems to be the ultimate theoretically lucerne hay quality model. However, the use of this model from a practical and economical view could be problematic. The following chemical parameters are needed to estimate TDN, namely, NDF, NDF-CP, ADF-CP, lignin, fat, ash and CP. As stipulated by Scholtz *et al*. (2009) only CP, NDF, ash and lignin produced accurate NIRS calibration equations for quality assurance. The remaining NIRS calibrations (NDF-CP, ADF-CP and fat) were less accurate than chemical analyses.

According to Zinn & Ware (2007) the most popular models for assessing the comparative feeding value of forages include: forage quality index (FQI), relative feed value (RFV) and relative forage quality (RFQ). The development and shortcomings of these models are well documented and defined in literature (Moore & Undersander, 2002; Zinn & Ware, 2007). According to Zinn & Ware (2007) all three approaches assess quality differences among forages according to DMI and digestibility and tend to rank forages similarly (Moore & Undersander, 2002). A positive strong significant (P <0.0001) correlation existed between these models (r >0.90; Table 1). The highest correlation was observed between FQI and RFQ (r = 0.95). Thus, the relative performance of these quality models was expected to be similar. In terms of correlations with MY, FQI marginally outperformed RFQ (r = 0.91 and r = 0.87, respectively).

Table 1 Correlation (r) matrix of quality models and milk yield (MY) [a]

					Quality Models			
	MY	TDNlig	TDN48	RFV	TFI	ATF	FQI	RFQ
MY	1							
TDNlig	0.98	1						
LMV	0.96	0.97						
TDN48	0.86	0.84	1					
RFV	0.78	0.78	0.71	1				
TFI	0.67	0.68	0.74	0.93	1			
ATFI	0.77	0.77	0.70	0.91	0.88	1		
FQI	0.91	0.90	0.87	0.90	0.83	0.82	1	
RFQ	0.87	0.86	0.92	0.91	0.89	0.83	0.95	1

[a] All correlations were significant (P <0.05).
MY - milk yield; TDNlig - total digestible nutrients calculated by using *in vitro* neutral detergent fibre digestibility procedure (NDFDlig), calculated from lignin, to calculate total digestible nutrients (TDN); TDN48 - total digestible nutrients calculated by using 48 hours *in vitro* neutral detergent fibre digestibility procedure (NDFD48) to calculate total digestible nutrients (TDN); LMV – lucerne milk value; RFV – relative feed value; TFI – total forage index; ATFI – adjusted total forage index; FQI – forage quality index; RFQ – relative forage quality.

However, according to the relationship with MY (r = 0.78), RFV as a practical model to determine lucerne hay quality was still inferior to the use of an individual chemical parameter like ADF (r = 0.82), and similar to NDF (r = 0.78) as proposed by Scholtz, (2008). The r and significance of estimating RFV from either NDF (r = 0.97; P <0.0001) or ADF (r = 0.93; P <0.0001), suggest that the advantage to be gained from the use of RFV as an indication of lucerne hay quality are small. Similarly, Putnam (2004) demonstrated that the relationship between the NDF level of lucerne hay and RFV was virtually perfect (r = 0.99).

FQI and RFV does not account for the CP content in the forage. It is based only on fibre levels and is therefore an index of forage digestibility and an estimate of energy value or energy intake potential (Taylor, 1997). The models TFI and LQI were developed and based on the same concept and format as RFV, but with the incorporation of CP as suggested by Hutjens (1995), to reflect more completely the nutritive value of the forage. The ATFI was developed from TFI by Erasmus (2000) by replacing CP with adjusted crude protein (ACP) to compensate for unavailable CP (ADF-CP). Failure to obtain improved MY predictions using TFI (r = 0.67) and ATFI (r = 0.77) rather than RFV (r = 0.78), however, suggested that there were no benefit to be gained by using quality models that include CP or ACP. Therefore, the benefit of lucerne hay protein could possibly be overvalued by several conventional grading models (RFQ, TFI and ATFI) due to its (CP) low relationship with MY (r = 0.2; Scholtz, 2008) and poor utilisation by ruminants (Martin & Mertens, 2005). The significant (P <0.0001) stronger correlation observe between ACP and MY (r = 0.62; Scholtz, 2008), compared to CP and MY (r = 0.19; Scholtz, 2008), was manifested in a stronger correlation of ATFI (r = 0.77) with MY, compared to TFI (r = 0.67) (Table 1).

A possible explanation for the negative effect of lucerne hay-CP on CP-containing quality models (TFI, ATFI) in predicting MY, could be due to its highly fermentable characteristic in the rumen. The rapid degradation in the rumen by microbes results in excessive excretion of nitrogenous waste by the animal (Martin & Mertens, 2005). These excessive levels of nitrogen in the rumen that are absorbed into the cow circulatory system, increases milk urea nitrogen (MUN) levels in the milk and filtering load placed on the kidneys (Van Soest, 1994). This process calls for additional energy usage that could have otherwise been used for milk production. Evidence from several experiments indicates that the protein in lucerne hay is utilised inefficiently by lactating dairy cows (Broderick *et al*., 1992). The CNCPS takes this into account, hence the possible decrease in available energy for milk production. Energy is the nutrient most limiting in diets of high producing dairy cows (Tylutki *et al*., 2008) and probably also the nutrient most apt to need supplementation in diets containing high levels of lucerne hay. Therefore, the importance of energy to animal production and its impact on limiting the level of lucerne hay that can be fed to high producers, would suggest that energy may be the most important criteria to use in evaluating the quality of lucerne hay.

Conclusions

From the evaluation results of the present study it seems that models for assessing lucerne hay quality revealed large differences in the accuracy of prediction as measured by MY. The best results were obtained with the summative TDN equation used by NRC (2001), followed by the LMV model. Nevertheless, with regard to costs of laboratory analysis and maintaining robust NIRS calibration equations, the use of the TDNlig model in predicting MY, although less population-specific (robust), would not be practical and economically viable compared to the accurate more simplistic LMV empirical equation. Thus, for commercial application, the LMV model will provide a means to make rapid, simplistic and accurate assessment of milk production potential, alias quality, of South African lucerne hay in practice.

The relative poor performance of ACP and CP containing quality models suggest that there is no benefit to be gained by including ACP or CP in quality models for assessing lucerne hay quality.

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