# Ruminal degradability of dry matter and neutral detergent fibre of grasses

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**ABSTRACT**: A study was conducted (I) to determine rumen degradability (*in sacco*) of dry matter (DM) and neutral detergent fibre (NDF) of the most important grass species grown in the Czech Republic, (II) to compare grass species ($n$ = 5) according to calculated degradation parameters, and (III) to establish prediction equations for degradation parameters from chemical composition. Forty samples of the most important grass species (*Dactylis glomerata*, *Phleum pratense*, *Lolium perenne*, *Festuca arundinacea*, Felina hybrid) were harvested in 2004 and 2005 and analyzed for chemical composition, and DM and NDF *in sacco* degradability. Results from the *in sacco* method were used to calculate DM and NDF degradation parameters. Linear and stepwise multiple regression analyses were used to develop prediction equations for DM and NDF degradation parameters from nutrient concentrations. The highest DM and NDF degradation parameters were found for *Lolium perenne*. DM and NDF rumen degradation parameters were successfully predicted from chemical composition, with a single predictor adequate for most parameters. For all parameters $R^2$-values increased with addition of more predictors into regression equations. Effective degradability (ED) of DM calculated at a rumen outflow rate ($k$) of 0.05 $h^{-1}$ was the best predicted by NDF ($R^2$ = 0.878), and ED of NDF at $k$ = 0.02 $h^{-1}$ by crude protein (CP) ($R^2$ = 0.653).

**Keywords**: rumen degradation parameters; dry matter; neutral detergent fibre; *in sacco* method; prediction equations

Forage production in the Czech Republic and Central Europe is dominated by grasses. However, there is a lack of information about ruminal degradability of dry matter (DM) and neutral detergent fibre (NDF) of the most important grass species grown in European countries. The rate and extent of DM fermentation in the rumen are crucial determinants of the nutrients utilized by ruminants (Kamalak et al., 2005). The main factor influencing the rate of fermentation of feeds is the structure of the carbohydrate fraction, especially the extent of lignification of the cell wall (Nagadi et al., 2000).

Rumen degradability is routinely determined by use of the *in sacco* method. This method is used for measuring of degradation parameters of a whole spectrum of nutrients and feeds (Čerešňáková et al., 2007; Homolka et al., 2007, 2008). However, the *in sacco* method requires rumen-cannulated animals, and is time consuming and expensive. These have resulted in a search for alternative methods to evaluate rumen digestibility. *In vitro* methods, such as gas production (Pozdíšek and Vaculová, 2008; Jalč et al., 2009), pepsin-cellulase solubility (Nousiainen et al., 2003a,b) and others (Cherney et al., 1993; López et al., 1998; Koukolová et al., 2004), are hampered by a need for rumen fluid from experimental animals, expensive chemicals and commercial enzymes. Other options to estimate digestibility are through prediction equations based on chemical composition. These prediction

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equations are an appropriate for institutions that lack experimental animals and equipment for *in vitro* digestibility analysis (Jančík et al., 2008). Prediction equations based on chemical composition have been successfully applied for different feeds and nutrients (Nousiainen et al., 2003a; Yan and Agnew, 2004; Andrés et al., 2005; Jančík et al., 2009; Villamide et al., 2009). However, adequate equations to predict DM and NDF rumen degradation parameters of grasses from chemical composition are lacking.

This study aimed (I) to determine rumen degradability of DM and NDF of the most important grass species grown in the Czech Republic, (II) to compare grass species ($n$ = 5) according to calculated degradation parameters, and (III) to compute prediction equations for degradation parameters from chemical composition. These would add to the present knowledge of DM and NDF rumen digestion kinetics of grass species commonly grown in the Czech Republic.

## MATERIAL AND METHODS

### Samples

Forty samples of five of the most frequently used grass species for ruminant nutrition in the Czech Republic (*Dactylis glomerata* L. – variety Dana, *Phleum pratense* L. – Sobol variety, *Lolium perenne* L. – Jaspis variety, *Festuca arundinacea* L. – Prolate variety and Felina hybrid) were evaluated. Grasses were grown as a monoculture at the Větrov Breeding Station, Tábor region, Czech Republic (49°31'2.04" N lat, 14°28'4.9" E long; 620 m altitude). They were harvested from primary growth at six dates in 2004 (May 13$^{th}$; May 19$^{th}$; May 26$^{th}$; June 2$^{nd}$; June 9$^{th}$; June 16$^{th}$) and at two dates in 2005 (May 20$^{th}$; June 3$^{rd}$). The samples were oven-dried at 50°C for 48 h and milled through a 1 mm screen.

### Chemical analysis

All samples ($n$ = 40) were analyzed for DM, crude protein (CP), ash, ether extract (EE), NDF, acid detergent fibre (ADF) and acid detergent lignin (ADL). DM was determined at 105°C for 12 h of oven-drying, and ash content after combusting at 550°C for 4.5 h (Regulation No. 497/2004, 2004). EE was extracted for 6 h with petroleum-ether. The Kjeldahl method was used for determination of nitrogen (N) (AOAC Official Method 976.05; AOAC, 2005), with content of CP calculated as N × 6.25. NDF was determined according to the methods of Van Soest et al. (1991), and ADF and ADL according to AOAC Official Method 973.18 (AOAC, 2005) adapted for an ANKOM 220 Fibre Analyzer (ANKOM Technology Corporation, NY, USA).

### *In sacco* procedure

Ruminal DM and NDF disappearances were estimated by the *in sacco* technique. Grass samples were incubated (three bags per sample per incubation time) in the rumen of two Holstein cows fitted with permanent rumen fistula. Rations of the fistulated cows consisted of ad lib meadow hay supplemented with 1 kg of barley meal per day and animal. Samples were weighed (1.5 g; 1 mm screen sieve) into nylon bags with a pore size of 42 μm (internal dimensions 50 × 120 mm) (Uhelon 130 T, Silk and Progress Moravská Chrastová). The nylon bags with the weighed samples were attached to a cylindrical carrier and incubated in the rumen for 6, 12, 24, 48, 72 and 96 h. Upon removal, bags were hand washed in cold water for 30 minutes. Zero time disappearances were obtained from washed nylon bags not subjected to rumen incubation. All washed nylon bags were dried in a forced-air oven at 50°C for 48 h.

The rumen degradation parameters of DM and NDF were calculated using the equations of Ørskov and McDonald (1979):

$$\text{Deg}_{\text{DM}(t)} = a + b \times (1 - \exp^{-ct})$$

$$\text{Deg}_{\text{NDF}(t)} = b \times (1 - \exp^{-ct})$$

where:

$\text{Deg}_{(t)}$ = disappearance of DM or NDF at time $t$

$a$ = intercept representing the portion of DM solubilized at the initiation of incubation (time 0)

$b$ = fraction of DM or NDF potentially degradable in the rumen

$c$ = rate constant of disappearance of fraction $b$

$t$ = time of incubation

The effective ruminal degradability of DM ($ED_{DM}$) and NDF ($ED_{NDF}$) were calculated according to Ørskov and McDonald (1979):

$$ED_{DM} = a + b \times (c/(c + k))$$
$$ED_{NDF} = b \times (c/(c + k))$$

where:

$k$ = ruminal outflow rate, being k = 0.05 $h^{-1}$ for $ED_{DM}$ (Ramírez et al., 2009)

$k$ = 0.02 $h^{-1}$ for $ED_{NDF}$ (Koukolová et al., 2004)

## Statistical analysis

The MIXED procedure of SAS (SAS, 2002–2003) was used to evaluate the influence of harvest dates and grass species on chemical composition, and DM and NDF degradation parameters. The effects of year and grass species were considered as fixed, and harvest date was nested in each level of the factor grass as a covariate. Because of heterogeneity of the variance the different variances for harvest dates were taken into account in the variance-covariance structure of the model. Changes in the chemical composition, and DM and NDF degradation parameters, at consecutive harvest dates were evaluated with Scheffe's pairwise comparison, adjusted with the Bonferroni correction to control the overall type I error rate (Rasch et al., 1999).

Linear and stepwise multiple regression analyses (Statistica 6, 2001) were used to develop prediction equations for DM and NDF degradation parameters from nutrient concentrations in grasses.

## RESULTS AND DISCUSSION

Chemical composition and degradation parameters of DM and NDF of grass samples are presented in Table 1. Chemical composition showed wide variation among grasses. Values ranged with 146.8 for CP, 199.8 for ADF, 330.9 for NDF and 30.5 g/kg for ADL between minimum and maxi-

Table 1. Chemical composition and degradation parameters of grass samples ($n$ = 40)

| | Mean | Minimum | Maximum | SD |
|---|---|---|---|---|
| **Chemical composition** (g/kg of DM) | | | | |
| Ash | 76.5 | 49.0 | 105.3 | 14.9 |
| EE | 21.0 | 5.4 | 42.6 | 7.8 |
| CP | 136.1 | 64.5 | 211.3 | 35.9 |
| CF | 286.0 | 171.5 | 373.8 | 46.6 |
| ADF | 298.9 | 183.0 | 382.8 | 44.4 |
| NDF | 550.2 | 360.3 | 691.2 | 68.2 |
| ADL | 21.4 | 10.9 | 41.4 | 6.6 |
| **DM degradation parameters** (g/kg of DM) | | | | |
| $a$ | 333.0 | 210.8 | 527.8 | 58.7 |
| $b$ | 557.0 | 430.1 | 679.6 | 47.0 |
| $c$ ($h^{-1}$) | 0.070 | 0.029 | 0.141 | 0.020 |
| $ED_{DM}$ ($k$ = 0.05 $h^{-1}$) | 651.5 | 483.5 | 844.7 | 79.2 |
| **NDF degradation parameters** (g/kg of NDF) | | | | |
| $b$ | 846.1 | 684.2 | 942.2 | 61.3 |
| $c$ ($h^{-1}$) | 0.077 | 0.039 | 0.108 | 0.016 |
| $ED_{NDF}$ ($k$ = 0.02 $h^{-1}$) | 668.0 | 503.0 | 784.8 | 71.3 |

ADF = acid detergent fibre; ADL = acid detergent lignin; CF = crude fibre; CP = crude protein; DM = dry matter; EE = ether extract; NDF = neutral detergent fibre; $a$ = portion of DM solubilized at the initiation of incubation (time 0); $b$ = fraction of DM or NDF potentially degradable in the rumen; $c$ = rate constant of disappearance of fraction $b$; $k$ = ruminal outflow rate; $ED_{DM}$ = effective ruminal degradability of DM; $ED_{NDF}$ = effective ruminal degradability of NDF; SD = standard deviation mum. Comparable results were reported by Cherney et al. (1993) for *Phleum pratense* and *Festuca arundinacea*, López et al. (1998) for grass hay, Jensen et al. (2003) for *Dactylis glomerata* and *Lolium perenne* and Sommer et al. (2005) for meadow hay.

Similarly, DM degradation parameters showed large differences between the lowest and highest values, with differences of 317 g/kg of DM, 249.5 g/kg of DM, 0.112 $h^{-1}$ and 361.2 g/kg of DM for *a*, *b*, *c* and ED, respectively. Yu et al. (2004) found that *a* varied from 169 to 213 g/kg of DM, *b* from 431 to 577 g/kg of DM, *c* from 0.026 to 0.059 $h^{-1}$, and $ED_{DM}$ from 609 to 698 g/kg of DM in *Phleum pratense*. $ED_{DM}$ values of 470 and 560 g/kg DM were reported for meadow hay (Rymer and Givens, 2002) and *Festuca arundinacea* (Elizalde et al., 1999), respectively. With different forages, Coblentz et al. (1998) stated values of 189 to 268 g/kg of DM, 469 to 536 g/kg of DM, and 0.031 to 0.056 $h^{-1}$ for *a*, *b*, and *c*, respectively. According to Gosselink et al. (2004), *Lolium perenne* presented an *a* of 248 and a *b* of 550 g/kg of DM, with 0.053 $h^{-1}$ found for *c*.

The NDF degradation parameters *b*, *c* and ED differed with 258 g/kg of NDF, 0.069 $h^{-1}$ and 281.8 g/kg of NDF, respectively, between minimum and maximum values. A range of 595 to 752 g/kg of NDF for *b* and 0.032 to 0.056 $h^{-1}$ for *c* were reported for *Tripsacum dactyloides* (Coblentz et al., 1998). *Lolium multiflorum* was characterized by a *b* value of 598 g/kg NDF and *c* value of 0.0291 $h^{-1}$ (Andrighetto et al., 1993).

Table 2. Comparison of chemical composition, dry matter (DM) and neutral detergent fibre (NDF) rumen degradation parameters of grass species

| | *Dactylis glomerata* | *Phleum pratense* | *Lolium perenne* | *Festuca arundinacea* | Felina hybrid |
|---|---|---|---|---|---|
| **Chemical composition** | | | | | |
| Ash[1] | 73.2[b] | 58.8[a] | 94.4[c] | 79.3[b,c] | 78.0[b,c] |
| EE[1] | 25.8[b] | 26.5[b] | 26.6[b] | 18.8[a,b] | 19.4[a] |
| CP[1] | 131.7[b] | 127.1[a,b] | 143.9[b] | 148.9[b] | 95.5[a] |
| CF[1] | 293.0[a,b] | 283.5[a,b] | 245.5[a] | 264.1[a,b] | 297.8[b] |
| ADF[1] | 314.9[b,c] | 331.4[c] | 257.8[a] | 279.9[a,b] | 308.3[b] |
| NDF[1] | 563.1[b,c] | 595.2[c] | 468.0[a] | 525.5[a,b] | 569.3[b,c] |
| ADL[1] | 27.7[b] | 22.6[a,b] | 20.6[a,b] | 19.8[a] | 20.3[a] |
| **DM degradation parameters** | | | | | |
| *a*[2] | 309.2[b] | 280.2[a] | 395.8[d] | 347.7[c] | 316.4[b] |
| *b*[3] | 537.8[a] | 616.6[b] | 530.3[a] | 540.7[a] | 540.1[a] |
| *c*[4] | 0.0712[b] | 0.0704[b] | 0.0911[c] | 0.0753[b] | 0.0592[a] |
| $ED_{DM}$[5] | 620.0[a,b] | 630.4[b] | 736.2[d] | 666.3[c] | 609.3[a] |
| **NDF degradation parameters** | | | | | |
| *b*[3] | 794.4[a] | 867.1[c] | 886.4[d] | 839.2[b] | 816.0[a,b] |
| *c*[4] | 0.078[b] | 0.084[b] | 0.101[c] | 0.085[b] | 0.066[a] |
| $ED_{NDF}$[5] | 630.9[a] | 689.0[c] | 740.7[d] | 674.0[b] | 619.4[a] |

[1]portion of dry matter solubilized at the initiation of incubation (time 0), (g/kg of DM)
[2]fraction of dry matter (g/kg of DM) or neutral detergent fibre (g/kg of NDF) potentially degradable in the rumen
[3]rate constant of disappearance of fraction *b* ($h^{-1}$)
[4]effective ruminal degradability of dry matter ($ED_{DM}$) (g/kg of DM) and neutral detergent fibre ($ED_{NDF}$) (g/kg of NDF) calculated with ruminal solid outflow rate (*k*) 0.05 $h^{-1}$ ($ED_{DM}$) and 0.02 $h^{-1}$ ($ED_{NDF}$)
[a,b,c,d]within a row means with different superscript letters are different ($P < 0.05$)

Table 2 shows mean values for chemical composition, and DM and NDF degradation parameters of the evaluated grass species. *Festuca arundinacea* contained the highest CP and lowest EE and ADL contents. On the contrary, the lowest CP content was found for the Felina hybrid. This grass showed the highest CF content. *Dactylis glomerata* presented the highest content of ADL. The lowest content of ash and the highest contents of ADF and NDF were detected in *Phleum pratense*. In contrast, the highest contents of ash and EE and the lowest contents of CF, ADF and NDF were found in *Lolium perenne*. In agreement to present results, Skládanka et al. (2008) detected higher NDF and lower ADF contents in the Felina hybrid compared to *Dactylis glomerata*. However, in contrast to our results, Skládanka et al. (2008) showed better quality (according to chemical composition) for the Felina hybrid than for *Festuca arundinacea*.

The highest sum of DM soluble (parameter *a*) and degradable (parameter *b*) components was calculated for *Lolium perenne* (926.1 g/kg DM). This grass also presented the highest values for *c* and $ED_{DM}$. *Dactylis glomerata* showed the lowest sum of DM soluble and degradable components ($a + b$), with the lowest *c* and $ED_{DM}$ values found in the Felina hybrid (Table 2). Wilman and Ahmad (1999) show a similar tendency for organic matter digestibility of *Lolium perenne* when compared to *Festuca arundinacea*.

NDF rumen degradation parameters (Table 2) were in agreement to DM rumen degradation parameters in the order of quality: *Lolium perenne*, *Phleum pratense*, *Festuca arundinacea*, Felina hybrid and *Dactylis glomerata*. Higher NDF digestibility of *Festuca arundinacea* in comparison with a grass hybrid (Hykor) was described by Pozdíšek et al. (2003).

Changes in DM and NDF rumen degradation parameters at harvest dates calculated for each of the grass species are presented in Table 3. The values describe a decrease in degradation parameters during 7 days of maturing (time between neighbouring harvests). The ruminal degradation parameters of observed grass species decreased linearly with increasing date of harvest. *Dactylis glomerata* had the lowest changes in DM degradation for the parameters *a* and *c* in comparison with the other grass species. *Festuca arundinacea* presented the lowest changes in the potential degradable component of DM (parameter *b*). For both $ED_{DM}$ and $ED_{NDF}$ the lowest changes were determined for *Lolium*

Table 3. Changes in dry matter (DM) and neutral detergent fibre (NDF) ruminal degradation parameters of grass species in relation to maturity (different dates of harvest)[1]

| | *Dactylis glomerata* | *Phleum pratense* | *Lolium perenne* | *Festuca arundinacea* | *Felina* hybrid |
|---|---|---|---|---|---|
| **DM degradation parameters** | | | | | |
| $a^2$ | $-16.07^{a}$ | $-21.55^{a}$ | $-18.68^{a}$ | $-22.57^{a}$ | $-16.15^{a}$ |
| $b^3$ | $-14.34^{b}$ | $-2.016^{a}$ | $-3.365^{a}$ | $-1.334^{a}$ | $-16.65^{b}$ |
| $c^4$ | $-0.0062^{a}$ | $-0.0086^{a}$ | $-0.0070^{a}$ | $-0.0085^{a}$ | $-0.0064^{a}$ |
| $ED_{DM}{}^5$ | $-35.98^{a,b}$ | $-40.91^{b}$ | $-28.40^{a}$ | $-37.53^{a,b}$ | $-40.01^{b}$ |
| **NDF degradation parameters** | | | | | |
| $b^3$ | $-35.46^{c,d}$ | $-18.36^{a}$ | $-23.40^{a,b}$ | $-27.04^{b,c}$ | $-38.78^{d}$ |
| $c^4$ | $-0.0071^{a,b}$ | $-0.0121^{b}$ | $-0.0100^{a,b}$ | $-0.0099^{a,b}$ | $-0.0065^{a}$ |
| $ED_{NDF}{}^5$ | $-40.95^{b,c}$ | $-35.29^{a,b}$ | $-29.26^{a}$ | $-37.05^{a,b,c}$ | $-45.65^{c}$ |

[1]values show how much parameters decreased during 7 days (between neighbouring harvests) of maturation
[2]portion of dry matter solubilized at the initiation of incubation (time 0), (g/kg of DM)
[3]fraction of dry matter (g/kg of DM) or neutral detergent fibre (g/kg of NDF) potentially degradable in the rumen
[4]rate constant of disappearance of fraction *b* ($h^{-1}$)
[5]effective ruminal degradability of dry matter ($ED_{DM}$) (g/kg of DM) and neutral detergent fibre ($ED_{NDF}$) (g/kg of NDF) calculated with ruminal solid outflow rate (*k*) 0.05 $h^{-1}$ ($ED_{DM}$) and 0.02 $h^{-1}$ ($ED_{NDF}$)
[a,b,c,d]within a row means with different superscript letters are different ($P < 0.05$)

Table 4. Prediction equations of grass dry matter (DM) degradation parameters, units are in g/kg of DM; the data subscripted within parentheses are standard error values

| Equation | RMSE | $R^2$ |
|---|---|---|
| ***a***[1] | | |
| $y = 226.9_{(32.07)} + 0.779_{(0.228)}$ CP | 51.72 | 0.235 |
| $y = 582.9_{(41.10)} - 0.874_{(0.142)}$ CF | 41.83 | 0.500 |
| $y = 759.9_{(30.05)} - 0.776_{(0.054)}$ NDF | 23.39 | 0.844 |
| $y = 691.5_{(24.26)} - 1.199_{(0.080)}$ ADF | 22.55 | 0.855 |
| $y = 444.8_{(25.26)} - 5.230_{(1.129)}$ ADL | 47.27 | 0.361 |
| $y = 781.5_{(42.18)} - 0.308_{(0.122)}$ CP $- 1.360_{(0.098)}$ADF | 21.10 | 0.876 |
| $y = 684.9_{(23.26)} + 0.301_{(0.135)}$ CF $- 1.465_{(0.141)}$ ADF | 21.46 | 0.872 |
| $y = 730.2_{(29.87)} - 0.345_{(0.166)}$ NDF $- 0.695_{(0.256)}$ ADF | 21.64 | 0.870 |
| $y = 706.6_{(25.08)} - 1.347_{(0.114)}$ ADF $+ 1.361_{(0.765)}$ ADL | 21.94 | 0.866 |
| $y = 810.8_{(43.18)} - 0.893_{(0.253)}$ ADF $- 0.288_{(0.118)}$ CP $- 0.312_{(0.157)}$ NDF | 20.31 | 0.888 |
| ***b***[2] | | |
| $y = 525.4_{(26.48)} + 0.232_{(0.188)}$ CP | 42.71 | 0.038 |
| $y = 530.9_{(42.58)} +0.091_{(0.147)}$ CF | 43.33 | 0.010 |
| $y = 438.6_{(52.50)} + 0.215_{(0.095)}$ NDF | 40.87 | 0.120 |
| $y = 474.9_{(44.86)} + 0.275_{(0.148)}$ ADF | 41.71 | 0.083 |
| $y = 581.1_{(22.91)} - 1.129_{(1.023)}$ ADL | 42.87 | 0.031 |
| $y = 210.8_{(74.45)} + 0.738_{(0.192)}$ CP $+ 0.447_{(0.101)}$ NDF | 35.02 | 0.371 |
| $y = 419.3_{(49.76)} - 0.610_{(0.242)}$ CF $+ 0.567_{(0.166)}$ NDF | 38.27 | 0.248 |
| $y = 419.6_{(56.53)} +0.491_{(0.315)}$ NDF $- 0.445_{(0.484)}$ ADF | 40.95 | 0.139 |
| $y = 383.2_{(46.46)} + 0.484_{(0.104)}$ NDF $- 4.322_{(1.073)}$ ADL | 34.54 | 0.388 |
| $y = 207.0_{(64.07)} + 0.627_{(0.099)}$ NDF $- 3.586_{(0.959)}$ ADL $+ 0.601_{(0.169)}$ CP | 30.13 | 0.546 |
| ***c***[3] | | |
| $y = 0.02881_{(0.0092)} + 0.00031_{(0.00007)}$ CP | 0.0149 | 0.364 |
| $y = 0.16804_{(0.0088)} - 0.00034_{(0.00003)}$ CF | 0.0090 | 0.768 |
| $y = 0.19861_{(0.0116)} - 0.00023_{(0.00002)}$ NDF | 0.0090 | 0.766 |
| $y = 0.16970_{(0.0117)} - 0.00033_{(0.00004)}$ ADF | 0.0109 | 0.660 |
| $y = 0.09925_{(0.0087)} - 0.00135_{(0.00039)}$ ADL | 0.0162 | 0.242 |
| $y = 0.15729_{(0.0168)} + 0.00004_{(0.00005)}$ CP $- 0.00032_{(0.00004)}$ CF | 0.0090 | 0.772 |
| $y = 0.19271_{(0.0101)} - 0.00019_{(0.00005)}$ CF $- 0.00013_{(0.00003)}$ NDF | 0.0077 | 0.832 |
| $y = 0.17536_{(0.0094)} - 0.00026_{(0.00006)}$ CF $- 0.00011_{(0.00006)}$ ADF | 0.0087 | 0.788 |
| $y = 0.16838_{(0.0089)} - 0.00035_{(0.00004)}$ CF $+ 0.00012_{(0.00027)}$ ADL | 0.0091 | 0.770 |
| $y = 0.19996_{(0.0103)} - 0.00021_{(0.00005)}$ CF $- 0.00023_{(0.00006)}$ NDF $+ 0.00019_{(0.00009)}$ ADF | 0.0074 | 0.850 |

*perenne. Phleum pratense* and the Felina hybrid showed the lowest changes for *b* and *c* of the NDF fraction, respectively.

Differences among grass species might be related to differences in maturing of observed grasses. *Dactylis glomerata* and Felina hybrid are early

Table 4 to be continued

| Equation | RMSE | $R^2$ |
|---|---|---|
| **$ED_{DM}$[4]** | | |
| $y = 437.4_{(33.91)} + 1.573_{(0.241)}$ CP | 54.68 | 0.529 |
| $y = 1\,065.1_{(38.74)} - 1.446_{(0.134)}$ CF | 39.43 | 0.755 |
| $y = 1\,238.0_{(35.75)} - 1.066_{(0.064)}$ NDF | 27.82 | 0.878 |
| $y = 1\,138.2_{(31.04)} - 1.628_{(0.103)}$ ADF | 28.87 | 0.869 |
| $y = 831.2_{(29.65)} - 8.407_{(1.325)}$ ADL | 55.49 | 0.515 |
| $y = 1\,063.5_{(47.93)} + 0.565_{(0.124)}$ CP $- 0.889_{(0.065)}$ NDF | 22.55 | 0.922 |
| $y = 1\,223.8_{(33.38)} - 0.450_{(0.163)}$ CF $- 0.806_{(0.111)}$ NDF | 25.67 | 0.899 |
| $y = 1\,206.3_{(36.22)} - 0.605_{(0.202)}$ NDF $- 0.742_{(0.310)}$ ADF | 26.24 | 0.894 |
| $y = 1\,208.1_{(34.13)} - 0.921_{(0.077)}$ NDF $- 2.328_{(0.789)}$ ADL | 25.37 | 0.901 |
| $y = 1\,061.7_{(44.69)} - 0.803_{(0.069)}$ NDF $+ 0.500_{(0.118)}$ CP $- 1.716_{(0.669)}$ ADL | 21.02 | 0.934 |

[1]portion of dry matter solubilized at the initiation of incubation (time 0), (g/kg of DM)
[2]fraction of dry matter potentially degradable in the rumen (g/kg of DM)
[3]rate constant of disappearance of fraction $b$ ($h^{-1}$)
[4]effective ruminal degradability of dry matter ($ED_{DM}$) (g/kg of DM) calculated with ruminal solid outflow rate ($k$) 0.05 $h^{-1}$ ($ED_{DM}$)
RMSE = residual mean square error; $R^2$ = coefficient of determination

maturing grass species, whereas *Lolium perenne, Festuca arundinacea* and *Phleum pratense* are late maturing grasses.

Regression equations that describe the relationships between DM rumen degradation parameters and the chemical composition of grasses are presented in Table 4. According to $R^2$-values and residual mean square errors, ADF ($R^2 = 0.855$) and NDF ($R^2 = 0.844$) were found as the best single predictors of parameter *a*. Parameter *b* was the best predicted by NDF ($R^2 = 0.120$). However, a single predictor was non-significant for this parameter. A regression with three predictors (NDF, ADL, CP) presented a $R^2$ value of 0.546. Parameter *c* was adequately predicted using CF ($R^2 = 0.768$) or NDF ($R^2 = 0.766$). $ED_{DM}$ was best predicted by NDF ($R^2 = 0.878$), although all presented equations gave satisfactory predictions. NDF was also detected as the best $ED_{DM}$ predictor for grass silages by Jančík et al. (2009). Nousiainen et al. (2003a) found ADF as the best single predictor of organic matter digestibility of grass silages.

Table 5 indicates the regression equations that described the relationships between NDF rumen degradation parameters and chemical composition of evaluated grasses. Parameter *b* was the best predicted by ADL ($R^2 = 0.572$), whereas NDF presented a $R^2$ value as low as 0.301. The combination of CP and ADL predicted the parameter *b* with a $R^2$ value of 0.677. The best predictor of parameter *c* was CP ($R^2 = 0.607$). ADL has the lowest value ($R^2 = 0.212$) to predict *c*. $ED_{NDF}$ was best predicted by CP ($R^2 = 0.653$). NDF was found as inadequate ($R^2 = 0.484$) to describe this parameter. According to linear multiple regression the combination of CP and ADL was superior ($R^2 = 0.769$) to predict $ED_{NDF}$. This combination was found by Jančík et al. (2008) as adequate for prediction of the indigestible part of NDF, and for organic matter digestibility of regrowth grass silages by Nousiainen et al. (2003b). Use of a higher number of predictors yielded equations with higher $R^2$-values and lower residual mean square errors.

Generally, NDF was the best predictor of DM degradation parameters. NDF represents the total insoluble matrix fibre, and it is better related to rumination and passage compared to other chemical components (Van Soest, 1994). CF is not recommended for prediction, attributed to the fact that it is unrelated to any original structural cell wall component (Van Soest, 1994). However,

Table 5. Prediction equations of grass neutral detergent fibre (NDF) degradation parameters; the data subscripted within parentheses are standard error values

| Equations | RMSE | $R^2$ |
|---|---|---|
| ***b***[1] | | |
| $y = 691.2_{(29.07)} + 1.138_{(0.207)}$ CP | 46.88 | 0.444 |
| $y = 1\,055.0_{(51.37)} - 0.730_{(0.177)}$ CF | 52.28 | 0.309 |
| $y = 1\,117.2_{(67.56)} - 0.493_{(0.122)}$ NDF | 52.58 | 0.301 |
| $y = 1\,103.0_{(52.90)} - 0.859_{(0.175)}$ ADF | 49.19 | 0.388 |
| $y = 995.8_{(21.97)} - 7.002_{(0.982)}$ ADL | 41.12 | 0.572 |
| $y = 869.9_{(41.30)} + 0.643_{(0.186)}$ CP $- 5.206_{(1.009)}$ ADL | 36.24 | 0.677 |
| $y = 1\,038.1_{(40.25)} - 0.215_{(0.172)}$ CF $- 6.101_{(1.212)}$ ADL | 40.82 | 0.590 |
| $y = 1\,035.6_{(55.60)} - 0.097_{(0.125)}$ NDF $- 6.360_{(1.285)}$ ADL | 41.33 | 0.579 |
| $y = 1\,036.6_{(47.02)} - 0.210_{(0.214)}$ ADF $- 5.975_{(1.435)}$ ADL | 41.14 | 0.583 |
| $y = 833.8_{(77.79)} + 0.689_{(0.206)}$ CP $+ 0.066_{(0.121)}$ NDF $- 5.517_{(1.165)}$ ADL | 36.58 | 0.679 |
| ***c***[2] | | |
| $y = 0.02884_{(0.0065)} + 0.00036_{(0.00005)}$ CP | 0.0105 | 0.607 |
| $y = 0.15185_{(0.0111)} - 0.00026_{(0.00004)}$ CF | 0.0113 | 0.551 |
| $y = 0.17382_{(0.0147)} - 0.00018_{(0.00003)}$ NDF | 0.0115 | 0.534 |
| $y = 0.15466_{(0.0129)} - 0.00026_{(0.00004)}$ ADF | 0.0120 | 0.493 |
| $y = 0.10163_{(0.0080)} - 0.00114_{(0.00036)}$ ADL | 0.0149 | 0.212 |
| $y = 0.08683_{(0.0171)} + 0.00024_{(0.00005)}$ CP $- 0.00015_{(0.00004)}$ CF | 0.0092 | 0.709 |
| $y = 0.09873_{(0.0193)} + 0.00024_{(0.00005)}$ CP $- 0.00010_{(0.00003)}$ NDF | 0.0091 | 0.717 |
| $y = 0.08015_{(0.0194)} + 0.00026_{(0.00006)}$ CP $- 0.00013_{(0.00005)}$ ADF | 0.0097 | 0.675 |
| $y = 0.03568_{(0.0121)} + 0.00034_{(0.00006)}$ CP $- 0.00020_{(0.00030)}$ ADL | 0.0106 | 0.612 |
| $y = 0.06824_{(0.0190)} + 0.00027_{(0.00005)}$ CP $- 0.00019_{(0.00007)}$ NDF $+ 0.00016_{(0.00011)}$ ADF | 0.0089 | 0.733 |
| **$ED_{NDF}$**[3] | | |
| $y = 449.6_{(26.72)} + 1.605_{(0.190)}$ CP | 43.08 | 0.653 |
| $y = 980.3_{(50.25)} - 1.092_{(0.173)}$ CF | 51.14 | 0.511 |
| $y = 1\,067.7_{(67.48)} - 0.727_{(0.122)}$ NDF | 52.52 | 0.484 |
| $y = 1\,019.0_{(53.55)} - 1.174_{(0.177)}$ ADF | 49.80 | 0.536 |
| $y = 831.1_{(27.56)} - 7.628_{(1.231)}$ ADL | 51.57 | 0.503 |
| $y = 654.9_{(72.77)} + 1.179_{(0.224)}$ CP $- 0.515_{(0.172)}$ CF | 39.17 | 0.721 |
| $y = 693.8_{(82.78)} + 1.212_{(0.214)}$ CP $- 0.347_{(0.112)}$ NDF | 38.94 | 0.724 |
| $y = 685.6_{(77.13)} + 1.142_{(0.223)}$ CP $- 0.579_{(0.180)}$ ADF | 38.59 | 0.729 |
| $y = 596.7_{(40.54)} + 1.197_{(0.183)}$ CP $- 4.286_{(0.991)}$ ADL | 35.58 | 0.769 |
| $y = 686.7_{(65.05)} + 1.028_{(0.203)}$ CP $- 3.546_{(1.055)}$ ADL $- 0.290_{(0.166)}$ CF | 34.64 | 0.787 |

[1]fraction of neutral detergent fibre (g/kg of NDF) potentially degradable in the rumen
[2]rate constant of disappearance of fraction $b$ ($h^{-1}$)
[3]effective ruminal degradability of neutral detergent fibre ($ED_{NDF}$) (g/kg of NDF) calculated with ruminal solid outflow rate ($k$) 0.02 $h^{-1}$ ($ED_{NDF}$)
RMSE = residual mean square error; $R^2$ = coefficient of determination

Table 6. Prediction equations of grass dry matter DM degradation parameters calculated for each species, units are in (g/kg of DM); the data subscripted within parentheses are standard error values

| Grass | Equation | RMSE | $R^2$ |
|---|---|---|---|
| ***a***[1] | | | |
| *Dactylis g.* | $y = 576.8_{(32.94)} - 0.843_{(0.104)}$ ADF | 10.68 | 0.917 |
| | $y = 509.4_{(71.35)} - 1.387_{(0.524)}$ ADF + $0.420_{(0.396)}$ NDF | 10.57 | 0.932 |
| *Phleum p.* | $y = 661.6_{(46.48)} - 1.140_{(0.139)}$ ADF | 13.29 | 0.918 |
| | $y = 791.9_{(74.85)} - 1.411_{(0.176)}$ ADF $- 0.300_{(0.149)}$ CP | 10.82 | 0.955 |
| *Lolium p.* | $y = 710_{(92.89)} - 1.205_{(0.356)}$ ADF | 36.06 | 0.656 |
| | $y = 746.9_{(103.3)} - 1.840_{(0.802)}$ ADF + $6.421_{(7.225)}$ ADL | 36.71 | 0.703 |
| *Festuca a.* | $y = 658_{(32.47)} - 1.093_{(0.115)}$ ADF | 13.27 | 0.938 |
| | $y = 850.4_{(77.77)} - 1.468_{(0.166)}$ ADF $- 0.562_{(0.217)}$ CP | 9.49 | 0.974 |
| Hybrid | $y = 598.8_{(79.80)} - 0.904_{(0.257)}$ ADF | 23.01 | 0.673 |
| | $y = 554_{(46.57)} - 1.741_{(0.267)}$ ADF + $0.988_{(0.265)}$ CF | 12.97 | 0.913 |
| ***b***[2] | | | |
| *Dactylis g.* | $y = 686.7_{(124.2)} - 0.252_{(0.217)}$ NDF | 29.59 | 0.183 |
| | $y = 299.8_{(177.7)} + 1.130_{(0.447)}$ CP + $0.153_{(0.225)}$ NDF | 21.48 | 0.641 |
| *Phleum p.* | $y = 525.1_{(66.64)} + 0.152_{(0.110)}$ NDF | 17.88 | 0.241 |
| | $y = 322.3_{(47.58)} + 0.382_{(0.064)}$ NDF + $0.486_{(0.091)}$ CP | 7.60 | 0.886 |
| *Lolium p.* | $y = 360.3_{(90.68)} + 0.688_{(0.352)}$ CF | 37.87 | 0.389 |
| | $y = 313.6_{(103.5)} + 0.491_{(0.512)}$ CP + $0.582_{(0.371)}$ CF | 38.13 | 0.484 |
| *Festuca a.* | $y = 522.8_{(40.75)} + 0.075_{(0.146)}$ CF | 22.49 | 0.042 |
| | $y = 325_{(202)} + 0.657_{(0.657)}$ CP + $0.425_{(0.379)}$ CF | 22.49 | 0.201 |
| Hybrid | $y = 616.3_{(32.76)} - 3.610_{(1.595)}$ ADL | 29.55 | 0.461 |
| | $y = 488.1_{(192.7)} + 0.575_{(0.851)}$ ADF $- 6.147_{(4.109)}$ ADL | 30.99 | 0.506 |
| ***c***[3] | | | |
| Dactylis g. | $y = 0.225_{(0.023)} - 0.00028_{(0.00004)}$ NDF | 0.005 | 0.889 |
| | $y = 0.266_{(0.022)} - 0.00038_{(0.00005)}$ NDF + $0.00071_{(0.00027)}$ ADL | 0.004 | 0.954 |
| *Phleum p.* | $y = 0.218_{(0.022)} - 0.00025_{(0.00004)}$ NDF | 0.006 | 0.889 |
| | $y = 0.202_{(0.023)} - 0.00015_{(0.00008)}$ NDF $- 0.00015_{(0.00011)}$ CF | 0.005 | 0.921 |
| *Lolium p.* | $y = 0.236_{(0.024)} - 0.00031_{(0.00005)}$ NDF | 0.008 | 0.868 |
| | $y = 0.235_{(0.021)} - 0.00018_{(0.0001)}$ NDF $- 0.00025_{(0.00016)}$ ADF | 0.007 | 0.910 |
| *Festuca a.* | $y = 0.135_{(0.014)} - 0.00023_{(0.00005)}$ CF | 0.008 | 0.788 |
| | $y = 0.107_{(0.018)} - 0.00047_{(0.00013)}$ CF + $0.00033_{(0.00017)}$ ADF | 0.006 | 0.883 |
| Hybrid | $y = 0.015_{(0.0046)} + 0.00041_{(0.00004)}$ CP | 0.003 | 0.937 |
| | $y = 0.075_{(0.024)} + 0.00026_{(0.00007)}$ CP $- 0.00015_{(0.00006)}$ CF | 0.002 | 0.972 |

equations based on CF could be used when detergent analyses are not available. ADF does not represent all the insoluble fibre, but it is usually better correlated with digestibility than NDF or CF. Lignin is generally regarded as the principal factor limiting digestibility, but it does not affect

Table 6 to be continued

| Grass | Equation | RMSE | $R^2$ |
|---|---|---|---|
| **$ED_{DM}$**[4] | | | |
| *Dactylis g.* | $y = 1\,151.3_{(46.63)} - 1.686_{(0.147)}$ ADF | 15.12 | 0.956 |
| | $y = 1\,000.9_{(89.90)} - 1.433_{(0.183)}$ ADF $+ 0.513_{(0.276)}$ CP | 12.73 | 0.974 |
| *Phleum p.* | $y = 1\,317.7_{(56.41)} - 1.141_{(0.093)}$ NDF | 15.13 | 0.961 |
| | $y = 1\,168.7_{(62.32)} - 0.972_{(0.084)}$ NDF $+ 0.356_{(0.120)}$ CP | 9.96 | 0.986 |
| *Lolium p.* | $y = 1\,093.7_{(56.61)} - 1.394_{(0.217)}$ ADF | 21.97 | 0.873 |
| | $y = 1\,135.8_{(57.86)} - 0.793_{(0.436)}$ ADF $- 0.416_{(0.270)}$ NDF | 19.81 | 0.914 |
| *Festuca a.* | $y = 1\,325.6_{(49.66)} - 1.240_{(0.093)}$ NDF | 13.45 | 0.967 |
| | $y = 1\,239.1_{(56.23)} - 0.718_{(0.254)}$ NDF $- 0.681_{(0.317)}$ ADF | 10.62 | 0.983 |
| Hybrid | $y = 1\,237.6_{(34.76)} - 2.047_{(0.112)}$ ADF | 10.02 | 0.982 |
| | $y = 1\,161.8_{(54.70)} - 1.679_{(0.242)}$ ADF $- 1.948_{(1.167)}$ ADL | 8.80 | 0.989 |

[1]portion of dry matter solubilized at the initiation of incubation (time 0), (g/kg of DM)

[2]fraction of dry matter potentially degradable in the rumen (g/kg of DM)

[3]rate constant of disappearance of fraction *b* ($h^{-1}$)

[4]effective ruminal degradability of dry matter ($ED_{DM}$) (g/kg of DM) calculated with ruminal solid outflow rate (*k*) 0.05 $h^{-1}$ ($ED_{DM}$)

RMSE = residual mean square error; $R^2$ = coefficient of determination

all feed components. Non-cell wall components are not influenced by lignin, but they often can be highly correlated. As a result of encrustation, lignin affects mainly availability of cell wall polysaccharides (Van Soest, 1994). It was evident in the presented prediction equations of the NDF degradation parameter *b*, where ADL was detected as the best single predictor. Although parameter *c* of NDF degradation was the best predicted by CP, the chemical components CF, NDF and ADF as sole predictors presented near similar values for regression coefficients. A similar tendency obtained with $ED_{NDF}$ was caused by the profound influence of parameter *c* in the calculation of $ED_{NDF}$. A high correlation between CP and parameter *c* most likely occurred because of coassociation, when protein declines as grass matures and lignification proceeds (Van Soest, 1994; Nousiainen et al., 2003a).

Equations to predict DM and NDF degradation parameters from chemical composition for individual grass species are presented Tables 6 and 7, respectively. The best single predictor equation and equations with the best combination of two predictors are shown. Equations mostly correspond to equations presented in Tables 4 and 5. However, equations calculated for each species were more accurate (higher $R^2$ and lower RMSE) compared to equations that included data from all grasses. This could probably related to a low number of grass samples ($n = 8$).

## CONCLUSIONS

This study showed that *Lolium perenne* presented the highest DM and NDF rumen degradation parameters of all evaluated grass species. Furthermore, the study confirmed that DM and NDF rumen degradation parameters in grass species can be predicted from chemical composition with satisfactory accuracy. A single predictor was adequate to predict most of the degradation parameters. However, with combinations of chemical components used as predictors the accuracy of prediction equations will improve. It could be recommended that all prediction equations with $R^2 > 0.500$ can be applied in practice. For prediction of the DM degradation parameters *a*, *c* and $ED_{DM}$, the use of single prediction equation based on NDF is suggested. However, to predict the parameter *b*,

Table 7. Prediction equations of grass neutral detergent fibre (NDF) degradation parameters for each species; the data subscripted within parentheses are standard error values

| Grass | Equations | RMSE | $R^2$ |
|---|---|---|---|
| ***b***[1] | | | |
| *Dactylis g.* | $y = 976.8_{(26.22)} - 6.488_{(0.927)}$ ADL | 23.04 | 0.891 |
| | $y = 1\,021.3_{(63.35)} - 0.207_{(0.266)}$ CF $- 5.818_{(1.289)}$ ADL | 23.84 | 0.903 |
| *Phleum p.* | $y = 989.8_{(15.93)} - 5.470_{(0.707)}$ ADL | 11.67 | 0.909 |
| | $y = 921.9_{(37.97)} - 4.008_{(0.967)}$ ADL $+ 0.269_{(0.141)}$ CP | 9.72 | 0.947 |
| *Lolium p.* | $y = 659_{(44.62)} + 1.488_{(0.292)}$ CP | 22.76 | 0.813 |
| | $y = 619.2_{(62.61)} + 1.403_{(0.310)}$ CP $+ 0.207_{(0.225)}$ CF | 23.06 | 0.840 |
| *Festuca a.* | $y = 1\,193.4_{(81.99)} - 1.227_{(0.289)}$ ADF | 33.50 | 0.750 |
| | $y = 1\,256.8_{(93.95)} - 2.233_{(0.862)}$ ADF $+ 0.800_{(0.649)}$ CF | 32.13 | 0.808 |
| Hybrid | $y = 1\,010.7_{(23.27)} - 9.548_{(1.133)}$ ADL | 21.00 | 0.922 |
| | $y = 896.8_{(133.3)} + 0.512_{(0.589)}$ ADF $- 11.80_{(2.843)}$ ADL | 21.44 | 0.932 |
| ***c***[2] | | | |
| Dactylis g. | $y = 0.244_{(0.017)} - 0.00030_{(0.00003)}$ NDF | 0.004 | 0.941 |
| | $y = 0.265_{(0.028)} - 0.00044_{(0.00015)}$ NDF $+ 0.00020_{(0.0002)}$ ADF | 0.004 | 0.950 |
| *Phleum p.* | $y = 0.179_{(0.016)} - 0.00035_{(0.00006)}$ CF | 0.007 | 0.869 |
| | $y = 0.200_{(0.028)} - 0.00024_{(0.00013)}$ CF $- 0.00009_{(0.00010)}$ NDF | 0.007 | 0.888 |
| *Lolium p.* | $y = 0.052_{(0.013)} + 0.00026_{(0.00009)}$ CP | 0.007 | 0.620 |
| | $y = 0.067_{(0.022)} + 0.00024_{(0.00009)}$ CP $- 0.00056_{(0.00064)}$ ADL | 0.007 | 0.671 |
| *Festuca a.* | $y = 0.136_{(0.013)} - 0.00021_{(0.00005)}$ CF | 0.007 | 0.769 |
| | $y = 0.113_{(0.013)} - 0.00030_{(0.00005)}$ CF $+ 0.00245_{(0.00098)}$ ADL | 0.005 | 0.897 |
| Hybrid | $y = 0.018_{(0.009)} + 0.00043_{(0.00009)}$ CP | 0.007 | 0.803 |
| | $y = -0.011_{(0.024)} + 0.00057_{(0.00014)}$ CP $+ 0.00075_{(0.00057)}$ ADL | 0.006 | 0.854 |
| **$ED_{NDF}$**[3] | | | |
| Dactylis g. | $y = 828.2_{(29.41)} - 7.239_{(1.04)}$ ADL | 25.84 | 0.890 |
| | $y = 950.4_{(44.71)} - 0.568_{(0.188)}$ CF $- 5.402_{(0.909)}$ ADL | 16.82 | 0.961 |
| *Phleum p.* | $y = 1\,188.2_{(49.43)} - 1.509_{(0.148)}$ ADF | 9.516 | 0.979 |
| | $y = 1\,155.5_{(35.17)} - 0.987_{(0.207)}$ ADF $- 0.480_{(0.167)}$ CF | 9.520 | 0.979 |
| *Lolium p.* | $y = 487.1_{(44.33)} + 1.580_{(0.290)}$ CP | 22.62 | 0.832 |
| | $y = 446.3_{(61.86)} + 1.493_{(0.306)}$ CP $+ 0.212_{(0.222)}$ CF | 22.79 | 0.858 |
| *Festuca a.* | $y = 1\,066.1_{(44.87)} - 1.399_{(0.158)}$ ADF | 18.33 | 0.929 |
| | $y = 1\,153.7_{(96.68)} - 0.866_{(0.545)}$ ADF $- 0.446_{(0.437)}$ NDF | 18.27 | 0.941 |
| Hybrid | $y = 1\,284.6_{(89.55)} - 2.153_{(0.289)}$ ADF | 25.82 | 0.903 |
| | $y = 931.5_{(227.5)} - 1.353_{(0.546)}$ ADF $+ 1.038_{(0.627)}$ CP | 22.74 | 0.937 |

[1]fraction of neutral detergent fibre (g/kg of NDF) potentially degradable in the rumen

[2]rate constant of disappearance of fraction *b* ($h^{-1}$)

[3]effective ruminal degradability of neutral detergent fibre ($ED_{NDF}$) (g/kg of NDF) calculated with ruminal solid outflow rate (*k*) 0.02 $h^{-1}$ ($ED_{NDF}$)

RMSE = residual mean square error; $R^2$ = coefficient of determination a prediction equation based on a combination of three predictors (NDF, ADL and CP) is needed. With NDF degradation parameters, prediction equations based on two predictors were found to be the most accurate. Presented prediction equations were developed with a large and comprehensive data set, therefore they can be recommended for practical application. However, more research is needed to investigate the relationships between chemical composition and degradation parameters for dried or ensiled grasses, legumes and other forages.

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