APPARENT DIGESTIBILITY OF NITROGEN AND NITROGEN RETENTION OF FORAGES FED TO STEERS IN METABOLISM STALLS

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ABSTRACT

Holstein steers in metabolism stalls were utilized to determine apparent digestibility of N (DN), N retention (NR) expressed as a percentage of total N consumed, and Mcal/kg digestible energy (DE) when diets of seven different classes of forages were fed. The best predictive equation for digestibility of N in the 153 forages studied was DN(%) = -98.1065 + 11.4724 (%CP) + 41.4475 (DE) - .1498 (%CP)² - 1.2541 (DE)² - 1.9309 (CP) (DE), with R² = .74 and sₓₓ = 8.63, where %CP is the percent crude protein of the forage. The best predictive equation for DN of sorghum silages, corn silages, legume hays and temperate grass hays contained both %CP and DE as predictor variables. The best predictive equations for DN of sorghum-sudan and bermudagrass hays contained only %CP and (%CP)² as predictor variables. The predictive equation for DN of 14 alfalfa hays involved only the linear relationship to %CP. The best scheme for predicting NR as a percentage of N consumed in 116 forages was a combination of three equations as follows: 1) NR(%) = -47.0797 + 6.4733 (%CP) - .1542 (%CP)² for forages, where DE = <2.42 Mcal/kg; 2) NR(%) = -67.6306 + 10.1354 (%CP) - .2726 (%CP)², where DE = 2.42 - 2.87 Mcal/kg; and 3) NR(%) = 28.3458 + 4.4722 (%CP) - .1263 (%CP)², where DE = >2.87 Mcal/kg; R² = .42 and sₓₓ = 14.86. Prediction equations for NR from data on corn silage and cereal silage and for alfalfa hays were not statistically significant for the predictor variables used in this study. The best equation for predicting NR in sorghum silages, legume hays, temperate grass hays and bermudagrass hays contained both %CP and DE as predictor variables, and in sorghum-sudan hays only %CP and (%CP)² were used. These data indicate that DN and NR in steers on forage diets exhibit a curvilinear relationship to %CP, and that increased precision is obtained by adding DE in calculating predictive equations for most groups of forages.

(Key Words: Forage, Digestible Protein, Nitrogen Retention, Digestible Energy, Prediction.)

Introduction

An overriding influence on the coefficient of digestibility of crude protein (CP) is the effect of metabolic fecal N. Many research workers have reported linear equations for predicting digestible protein (DP) from CP (N x 6.25; Holter and Reid, 1959; Stallcup and Davis, 1965; Knight and Harris, 1966; Anderson and Lamb, 1967; Preston, 1982). Data from metabolism trials with steers fed 68 forages were summarized (Stallcup et al., 1975). Significant correlations were found between total fecal N (FN) and dry matter (DM) intake (R = .93); between FN and total N intake (R = .90); and between FN and total fecal DM (R = .95). However, at high and low levels of N intake (NI), there was a departure from a linear relationship between NI and FN.

A summary of digestion and metabolism trials on 113 forages averaging 11.4% CP ranging from 4.1 to 25.4% revealed that the equation having the least error mean square for predicting digestibility % N (DN) was: DN(%) = -98.1065 + 11.4724 (%CP) + 41.4475 (DE) - .1498 (%CP)² - 1.2541 (DE)² - 1.9309 (CP) (DE), with R² = .74 and sₓₓ = 8.63, where %CP is the percent crude protein of the forage. The best predictive equation for DN of sorghum silages, corn silages, legume hays and temperate grass hays contained both %CP and DE as predictor variables. The best predictive equations for DN of sorghum-sudan and bermudagrass hays contained only %CP and (%CP)² as predictor variables. The predictive equation for DN of 14 alfalfa hays involved only the linear relationship to %CP. The best scheme for predicting NR as a percentage of N consumed in 116 forages was a combination of three equations as follows: 1) NR(%) = -47.0797 + 6.4733 (%CP) - .1542 (%CP)² for forages, where DE = <2.42 Mcal/kg; 2) NR(%) = -67.6306 + 10.1354 (%CP) - .2726 (%CP)², where DE = 2.42 - 2.87 Mcal/kg; and 3) NR(%) = 28.3458 + 4.4722 (%CP) - .1263 (%CP)², where DE = >2.87 Mcal/kg; R² = .42 and sₓₓ = 14.86. Prediction equations for NR from data on corn silage and cereal silage and for alfalfa hays were not statistically significant for the predictor variables used in this study. The best equation for predicting NR in sorghum silages, legume hays, temperate grass hays and bermudagrass hays contained both %CP and DE as predictor variables, and in sorghum-sudan hays only %CP and (%CP)² were used. These data indicate that DN and NR in steers on forage diets exhibit a curvilinear relationship to %CP, and that increased precision is obtained by adding DE in calculating predictive equations for most groups of forages.

(Key Words: Forage, Digestible Protein, Nitrogen Retention, Digestible Energy, Prediction.)

1 Published with approval of the Director of the Arkansas Agric. Exp. Sta.
2 Dept. of Anim. Sci.
Received November 10, 1986.
Accepted July 8, 1987.

Materials and Methods

Data on apparent DN and DE were obtained from feeding 153 forages in digestion and metabolism stalls. Some nutritive measurements of the forage groups included in this study are in Table 1. Nitrogen retention data were obtained on 116 forages. The forages fed were 15 corn silages (Zea mays), 30 sorghum silages (Sorghum vulgare), 22 legume hays, 11 cereal silages, 13 hays made from sorghum-sudan hybrid plants (Sorghum vulgare), 41 bermudagrass hays (Cynadon dactylon) and 21 hays made from various temperate grasses. The legume hay group was composed of 14 lots of alfalfa hay (Medicago sativa) and 8 lots of soybean hay (Glycine max). The 14 alfalfa hays were subjected to summary analysis in the legume groups and analyzed as a separate group in this study. The temperate grasses were made up of three lots of fescue hay (Festuca arundinacea), two lots of orchardgrass (Dactylis glomerata), 12 lots of plains bluestem hay (Bothriochloa ischaemum), one lot of prairie hay (Andropogon schparius), two lots of Brome hays (Bromus inermis Leyss and Bromus secalicus L.) and one lot of ryegrass (Lolium multiflorum). The cereal silages included one lot of wheat (Triticum aestivum), eight lots of oats (Avena sativa), and two lots of triticale, an interspecific cross between wheat (Triticum duruss) and rye (Secale cereals).

Silages were fed as they came from the silo. Most hays were chopped to lengths of 3.8 cm before feeding. Each forage was fed to a minimum of three Holstein steers (usually four or six) in metabolism stalls. Each forage was fed for a 14-d preliminary period and a 5-d period when a total collection of both feces and urine was made. The mean body weight of the steers used was 225.4 kg (SD = 15.9). The mean daily DM intake per steer was 4.5 ± 1.7 kg.

Holstein steers selected for metabolism trials were of approximately the same age and size. In addition, steers were screened for uniformity of feed intake, digestibility and rate of passage by feeding all steers a standard forage diet similar to those to be fed and under the same experimental conditions as those utilized in the trials. The steers were confined in metabolism stalls in a temperature-controlled room at 21 C and 50% relative humidity, or, in trials in later years, steers were housed in a temperature-controlled barn during the cool months of October to May. Samples of forages and of orts were taken daily and composited by collection period for chemical analysis. A 5% aliquot of daily fecal output for each steer was frozen immediately for further chemical analysis. Urine was collected in plastic vessels containing either toluene or containing sufficient 6 N HCl to maintain a pH below 2.0. Urine was measured by volume, specific gravity was determined, and a daily aliquot sample was retained for analysis of N. Daily fecal samples were thawed and pooled to yield individual steer composites for chemical analysis. Fecal samples then were dried at 50 C in a forced-air oven. Dry matter and N determinations were made on feed and feces and N in urine according to AOAC (1975) procedures.

The procedures used in the digestion trials are essentially those outlined by Harris (1970).

### Table 1. Crude Protein (CP), Digestible Energy (DE), Content of Forages and Digestibility of Nitrogen (DN) and Nitrogen Retention (NR) by Steers

<table>
<thead>
<tr>
<th>Forage group</th>
<th>No. of forages</th>
<th>CP (%)</th>
<th>DN (%)</th>
<th>NR (%)</th>
<th>DE (Mcal/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>X</td>
<td>SE</td>
<td>X</td>
<td>SE</td>
</tr>
<tr>
<td>Corn silage</td>
<td>15</td>
<td>8.1</td>
<td>.52</td>
<td>41.9</td>
<td>4.7</td>
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<tr>
<td>Sorghum silage</td>
<td>30</td>
<td>8.3</td>
<td>.49</td>
<td>39.9</td>
<td>3.4</td>
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<tr>
<td>Legume hay</td>
<td>22</td>
<td>19.1</td>
<td>1.13</td>
<td>66.3</td>
<td>3.4</td>
</tr>
<tr>
<td>Alfalfa hay</td>
<td>14b</td>
<td>21.5</td>
<td>4.00</td>
<td>70.7</td>
<td>5.3</td>
</tr>
<tr>
<td>Cereal silage</td>
<td>11</td>
<td>12.4</td>
<td>.90</td>
<td>61.3</td>
<td>1.7</td>
</tr>
<tr>
<td>Sorghum sudan</td>
<td>13</td>
<td>13.2</td>
<td>1.23</td>
<td>63.6</td>
<td>2.4</td>
</tr>
<tr>
<td>Temperate grass hay</td>
<td>21</td>
<td>11.2</td>
<td>.55</td>
<td>53.4</td>
<td>2.7</td>
</tr>
<tr>
<td>Bermudagrass hay</td>
<td>41</td>
<td>13.1</td>
<td>.68</td>
<td>55.5</td>
<td>1.5</td>
</tr>
<tr>
<td>All forages</td>
<td>153</td>
<td>12.3</td>
<td>.41</td>
<td>53.5</td>
<td>1.3</td>
</tr>
</tbody>
</table>

a Standard error of the mean.
b Alfalfa hays were included in legume hays and also analyzed separately.
The apparent digestion coefficient for N was calculated as follows: 

\[ \text{DN(\%)} = \left( \frac{N \text{ in forage consumed} - N \text{ in feces}}{N \text{ in forage consumed}} \right) \times 100. \]

All values were calculated to dry matter basis. The amount of forage refused was collected and weighed each day and subtracted from that offered. The orts were analyzed for N and gross energy (GE), and the appropriate subtractions were made to calculate N and DE consumed by the steers.

Gross energy was determined on dry forage and feces by means of a Parr adiabatic bomb calorimeter and accessories as outlined by Harris (1970). Digestible energy was calculated as follows: 

\[ \text{DE (mg/kg forage dry matter)} = \left( \frac{\text{GE of forage per unit dry weight} \times \text{dry weight of forage}}{\text{GE of feces per unit dry weight} \times \text{dry weight of feces}} \right) - \text{GE of feces per unit dry weight} \times \text{dry weight of feces}. \]

Water was available to steers at all times. Mineral supplementation consisted of dicalcium phosphate and trace mineralized salt free choice. The composition of the trace mineral salt was as follows: 96% NaCl; .3% Zn, .24% Mn; .22% Fe; .025% Cu; .007% I and .007% Co. Vitamin A supplementation was made in amounts to meet NRC (1976) recommendations. The trials were conducted over a period of 16 yr. Nitrogen retention as used in this study was calculated as follows: 

\[ \text{NR(\%)} = \left( \frac{N \text{ in forage} - N \text{ in feces} - N \text{ in urine}}{N \text{ in forage}} \right) \times 100. \]

The pooled data for each forage group and for a combined study of all forage groups were analyzed in an effort to determine the most useful regression equations for predicting the apparent DN and for NR by steers utilizing the %CP and DE content of the forages as predictor variables. The statistical analyses used included least-squares analysis for linearity, a quadratic equation to test curvilinearity of data, an exponential equation, 

\[ y = a + be^{-k(\% \text{CP})}, \]

and a combination of curvilinear relationships and interactions among predictor variables. Separate equations were used for three levels of DE in forages. The DE levels were 1) <2.42 Mcal/kg, 2) 2.42 - 2.87 Mcal/kg and 3) >2.87 Mcal/kg. These levels were arbitrarily chosen from actual data on DE on each forage as determined by a digestion trial. Level 2 represents the mean ± 1 SD of the mean for all forages studied, Level 1 was composed of DE values less than the minimum for range 2 and level 3 was composed of forages whose DE values were greater than the maximum for level 2.

### Results and Discussion

**Digestibility of Nitrogen (DN).** The best predictive equations for digestibility of N for each forage type studied are in table 2. The best predictive equation for corn silage was equation 1, which included both %CP and DE. The R² value (.73) was highly significant. However, the standard error of the estimate (s_y,x) was 10.58, which is rather large. The linear relationship between DN and %CP in corn silage had an R² value of .56; s_y,x was 12.53. Thus, equation 1 was much more accurate than the linear relationship reported previously (Stallcup and Davis, 1965). This group of corn silages was made up of many experimental hybrids, which may explain the heterogeneity of the sample as indicated by a standard error of DN of 4.7% (table 1).

The best predictive equation for DN in sorghum silage was equation 2, which included both %CP and DE content of silage, the curvilinearity of these components and the interaction CP × DE. The R² value was .80 (P<.01) and s_y,x was 9.14. These equations indicate that both CP and DE are both involved in the determination of DN, and that DN has a curvilinear relationship as well as a significant interaction between these two variables. The equation expressing the linear relationship between DN and %CP had an R² value of .40 (P<.01) with s_y,x of 14.72. Thus, the use of equation 2 resulted in a predictive equation associated with greater accuracy.

The best predictive equation for DN in legume hays were equations 3 and 4. Equation 3 includes the curvilinear relationship of DN to the %CP in hay. The R² value was .95 (P<.01), with s_y,x of 3.83. Equation 4 includes the curvilinear relationship with CP and DE as an additional predictor variable. This equation was associated with a R² value of .96 (P<.01) and s_y,x of 3.31, indicating a very high degree of accuracy for predicting DN. This may be compared with the linear equation for predicting DN from %CP in legume hay, which had an R² value of .66 (P<.01) but a much larger s_y,x of 9.44.

The best predictive equation for DN in alfalfa hays was equation 5: 

\[ \text{DN(\%)} = -46.0949 + 1.2470(\% \text{CP}) \]

\[ R^2 = .89 \text{ and } s_{y,x} = 1.78. \]
addition of DE to the predictive equation (equation 6) did not improve accuracy. The %CP is thus closely associated with DN in alfalfa hay. This fact is further substantiated by the high digestibility of N in alfalfa hay of 70.7% (table 1).

The best predictive equation for DN in sorghum-sudan hybrid hays (7) was DN(%) = 14.8852 + 6.6155(%CP) - 2.0092(%CP)^2. However the R^2 value was .39 (P<.10) and s_y,x was 8.55. Although this equation was not associated with as high degree of accuracy as those for alfalfa hay or legume hays, the relationship of DN to CP was curvilinear.

No predictive equations for DN were derived from the data on metabolism trials with cereal silages. This may have been due to the small number of silages involved and the low standard error (1.7) for DN (table 1).

The best equation for predicting DN in hay made from temperate grasses was equation 10 (table 2), which contains a curvilinear relationship to %CP and includes DE as a predictor variable. The R^2 value of .88 (P<.01) and the relatively low s_y,x of 4.77 indicate that this would be a useful equation. Equation 9, which includes CP and DE of forage as predictor variables but omits the curvilinearity of the relationship of DN to CP, was also significant (R^2 = .85) with a slightly higher s_y,x (5.16).

Other equations relating DN to CP in temperate grasses were: DN(%) = 12.7925 + 3.6112(%CP). The R^2 value was .53 (P<.01) and s_y,x was 8.90 and DN(%) = 47.4923 + 14.462(%CP) - .4644(%CP)^2. The R^2 value for this equation was .70 (P<.01) and s_y,x was 7.33. Equation 8, which includes the curvilinear relationships of both CP and DE and the interaction between CP and DE, had an R^2 value of .88 and s_y,x of 4.98. Equations containing DE as a predictor variable increased accuracy in predicting DN in the hays. Plains bluestem hays and prairie grass hay, of the temperate hay group and both made from warm-season perennial, were analyzed separately. The best predictive equation for DN in these hays were equations 11 and 12. The linear equation DN(%) = -9.7691 + 6.0755(%CP) was associated with a R^2 value of .78 (P<.01) and s_y,x of 6.13. Both of these values are less valid than the R^2 values of .93 and .94 and the s_y,x values of 3.50 and 3.85 for equations 11 and 12, respectively. Adding the analysis of any curvilinear relationship or the interaction between CP and DE contents of the hays as expressed in equation 12 did not add to the accuracy expressed by equation 10, where only DE and CP of hays were predictor variables.

The best predictive equations for bermudagrass hays DN are equations 13, 14 and 15 in table 2. An equation involving only CP in forage as a predictor variable was associated with a R^2 value of only .21 (P<.01) and a s_y,x value of 8.68. An equation including CP and DE as predictor variables was associated with a R^2 value of .28 (P<.01) and s_y,x of 8.40. Equations 14a, 14b and 14c, where an equation involving the curvilinear relationship of DN to CP for each of DE levels (<2.42, 2.42 to 2.87, and >2.87 Mcal/kg), resulted in the greatest degree of accuracy for predicting DN in bermudagrass hays. A more complex equation (15) involving curvilinear relationships of DN to both CP and DE and the interaction between these variables was not as accurate as a combination of equations 14a, 14b and 14c.

Equation 19 in table 3 predicts DN with the highest degree of accuracy of any of the statistical measures studied. It involves the curvilinear relationship of DN to both CP and DE and the interaction between these predictor variables. Equation 18, which embodies the curvilinear relationship of DN to CP and DE as a second predictor variable, was associated with a larger s_y,x (9.18 vs 8.63) than equation 19. Likewise, equation 17, which includes the curvilinear relationship of DN to CP and omits DE as a predictor variable, is associated with a lower R^2 value and larger s_y,x than equations 18 and 19, which include both CP and DE as predictor variables. Equation 16, which involves the linear relationship of DN to CP accounts for less of the total variance than equations 17, 18 and 19, as evidenced by a smaller R^2 value and larger s_y,x. These data indicate that on forage diets the digestibility of N is influenced by both CP and DE, and without energy or N supplementation a curvilinear relationship exists with lower DN at the lower and upper extremities of CP content of the forages studied, which varied from 4.1 to 27.2% (DM basis) with a mean of 12.3 and SE of .41%. Digestible energy determined by means of a Parr adiabatic calorimeter in analyzing forage and feces from steers in a metabolism stall is one of the most accurate determinations that can be made in a laboratory. Furthermore, it represents units of heat energy absorbed into the body of the animal and is not a mixture of digestible and indigestible substances as is the case of crude fiber, acid detergent fiber and neutral detergent fiber. The
<table>
<thead>
<tr>
<th>Forage</th>
<th>Equation</th>
<th>No. of forages</th>
<th>DE level&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Equation&lt;sup&gt;b&lt;/sup&gt;</th>
<th>$R^2$</th>
<th>$s_{y.x}$</th>
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<tbody>
<tr>
<td>Corn silage</td>
<td>1</td>
<td>15</td>
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<td>$DN(%) = -92.0268 + 13.9425(%CP) - 0.5767(%CP)^2 + 22.6513(DC)$</td>
<td>.73**</td>
<td>10.58</td>
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<td>Sorghum silage</td>
<td>2</td>
<td>30</td>
<td></td>
<td>$DN(%) = -39.4348 + 25.4712(%CP)$</td>
<td>.80**</td>
<td>9.14</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$-59.9519(DC) - 0.5648(%CP)^2 + 23.7187(DC)^2 - 4.3605(%CP)(DC)$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Legume hays</td>
<td>3</td>
<td>22</td>
<td></td>
<td>$DN(%) = 34.0796 + 9.3765(%CP) - 0.2011(%CP)^2$</td>
<td>.95**</td>
<td>3.83</td>
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<td></td>
<td>4</td>
<td>22</td>
<td></td>
<td>$DN(%) = 46.0949 + 8.6113(%CP) - 0.186(%CP)^2 + 8.3903(DC)$</td>
<td>.96**</td>
<td>3.31</td>
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<tr>
<td>Alfalfa hay</td>
<td>5</td>
<td>14</td>
<td></td>
<td>$DN(%) = 43.8023 + 1.2470(%CP)$</td>
<td>.89***</td>
<td>1.78</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>14</td>
<td></td>
<td>$DN(%) = 40.1154 + 1.2236(%CP) + 1.6564(DC)$</td>
<td>.90***</td>
<td>1.82</td>
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<tr>
<td>Sorghum-sudan</td>
<td>7</td>
<td>13</td>
<td></td>
<td>$DN(%) = 14.8852 + 6.6155(%CP) - 2.0092(%CP)^2$</td>
<td>.39*</td>
<td>6.80</td>
</tr>
<tr>
<td>Temperate grasses</td>
<td>8</td>
<td>21</td>
<td></td>
<td>$DN(%) = -106.3814 + 12.7149(%CP) + 39.4796(DC) - 0.1976(%CP)^2 - 0.2425(DC)^2 - 2.066(%CP)(DC)$</td>
<td>.88***</td>
<td>4.98</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>21</td>
<td></td>
<td>$DN(%) = 36.985 + 3.2010(%CP) + 20.4540(DC)$</td>
<td>.85***</td>
<td>5.16</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>21</td>
<td></td>
<td>$DN(%) = -57.5525 + 8.3416(%CP) - 2.176(%CP)^2 + 17.2980(DC)$</td>
<td>.88***</td>
<td>4.77</td>
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<td>Plains bluestem hays</td>
<td>11</td>
<td>13</td>
<td></td>
<td>$DN(%) = -55.3733 + 25.4393(DC) + 3.5899(%CP)$</td>
<td>.93***</td>
<td>3.50</td>
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<tr>
<td></td>
<td>12</td>
<td>13</td>
<td></td>
<td>$DN(%) = 149.8555 + 2.0692(%CP) - 113.6998(DC) - 0.8855(%CP)^2 + 9.7095(DC)^2 + 7.5463(%CP)(DC)$</td>
<td>.94***</td>
<td>3.85</td>
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Bermudagrass hays

<table>
<thead>
<tr>
<th>No.</th>
<th>13</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>DN(%) = −6.413 + 8.2644(%CP) − .2434(%CP)^2</td>
<td>.61***</td>
</tr>
<tr>
<td>14a</td>
<td>10</td>
<td>1</td>
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<td></td>
<td>DN(%) = −35.8088 + 13.9556(%CP) − 8.5175(%CP)^2</td>
<td>.67d***</td>
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<tr>
<td>14b</td>
<td>24</td>
<td>2</td>
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<tr>
<td></td>
<td>DN(%) = 28.2843 + 4.3077(%CP) − .1505(%CP)^2</td>
<td></td>
</tr>
<tr>
<td>14c</td>
<td>7</td>
<td>3</td>
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<tr>
<td></td>
<td>DN(%) = 23.9150 + 4.5817(%CP) − .1233(%CP)^2</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>41</td>
<td></td>
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<tr>
<td></td>
<td>DN(%) = 31.8004 + 8.6966(%CP) − 40.2186(DE) − .0156(%CP)^2 + 13.1796(DE)^2 − 1.3364(%CP)(DE)</td>
<td>.55***</td>
</tr>
</tbody>
</table>

\*a1 = <2.42 Mcal/kg, 2 = 2.42 to 2.87 Mcal/kg, 3 = >2.87 Mcal/kg.
\*bDN = Coefficient of digestibility of N; CP = crude protein calculated as N × 6.25; DE = digestible energy (Mcal/kg) as determined by digestion trials.
\*cStandard error of the mean.
\*dValues for R^2 and s_y.x when equations 14a, 14b and 14c are used to predict DN(%) at three levels of DE.
*P<.10.
**P<.01.
***P<.001.

### TABLE 3. THE BEST PREDICTIVE EQUATIONS FOR DIGESTIBILITY OF NITROGEN UTILIZING POOLED DATA ON ALL FORAGES

<table>
<thead>
<tr>
<th>Equation</th>
<th>No. of forages</th>
<th>Equation(^a)</th>
<th>R^2</th>
<th>(b) (s_y.x)</th>
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</thead>
<tbody>
<tr>
<td>16</td>
<td>153</td>
<td>DN(%) = 26.1146 + 2.336(%CP)</td>
<td>.47***</td>
<td>12.06</td>
</tr>
<tr>
<td>17</td>
<td>153</td>
<td>DN(%) = −9.9096 + 8.083(%CP) − .2029(%CP)^2</td>
<td>.63***</td>
<td>10.14</td>
</tr>
<tr>
<td>18</td>
<td>153</td>
<td>DN(%) = −37.2859 + 7.3796(%CP) − .1837(%CP)^2 + 12.3910(DE)</td>
<td>.70***</td>
<td>9.18</td>
</tr>
<tr>
<td>19</td>
<td>153</td>
<td>DN(%) = −98.1065 + 11.4724(%CP) + 41.4465(DE) − .1498(%CP)^2 − 1.2541(DE)^2 − 1.9309(CP)(DE)</td>
<td>.74***</td>
<td>8.63</td>
</tr>
</tbody>
</table>

\*DN = Coefficient of digestibility of N; CP = crude protein in forages calculated as N × 6.25; DE = digestible energy (Mcal/kg) as determined by digestion trials.
\*bStandard error of the mean.

***P<.001.
standard error of the mean \( (s_{y.x}) \) is larger in
the equation derived from pooled data (table 3)
than in equations derived from data obtained in
trials on legume hays, alfalfa hays, sorghum-
sudan hays, hays made from temperate grasses,
plains bluestem hays and bermudagrass hays.
However, equations derived from data on corn
silage trials and equation 2, derived from data
on sorghum silage trials, were associated with
higher \( s_{y,x} \) than equation 19 on pooled data.
These two silage groups had lower mean CP
content, 8.1 and 8.3 for corn and sorghum
silages, respectively, than the mean (12.3) for
pooled data. The alfalfa hays were the only
group studied where the simple linear equation

\[
DN(\%) = 43.8023 + 1.2470 \times CP(\%)
\]

was the most
accurate among the different predictor equa-
tions studied. This finding indicates that a
simple linear equation involving only CP as a
predictor variable should not be applied univer-
sally to all forages or to groups of forages. This
finding agrees with some previous work (Stall-
cup et al., 1975, 1984), and is at variance with
other work where simple correlations were used
to indicate significance of a predictor equation
containing only CP as the predictor variable and
did not involve comparisons with equations
containing %CP, \((%CP)^2\) and DE (Holter and
Reid, 1959; Stallcup and Davis, 1965; Knight
and Harris, 1966; Anderson and Lamb, 1967;
Preston, 1982).

Pearson correlation coefficients between
variables were calculated for each forage group
and for pooled data on all forages. DN was
significantly correlated \((P<.01)\) to forage
CP(\%), DE (Mcal/kg) and total digestible
nutrients (%) in corn silage, sorghum silage,
hays from temperate grasses, bermudagrass hays
and in pooled data on all forages. NR was
 correlated with CP(%) only in sorghum silages
\((P<.05)\) and in pooled data on all forages
\((P<.01)\). NR was correlated with DE (Mcal/kg)
in legume hay \((P<.01)\), in hays from temperate
grassess and in pooled data on all forages \((P<.01)\).
NR was significantly correlated with total
digestible nutrients (%) in legume hays and hays
made from temperate grasses. These data
indicate that pooled data may or may not be
indicative of the relationships between DN and
NR in various forage groups.

Balch (1967) has presented diagrams indicat-
ing a rectilinear response in N balance to
increments of protein in diets in which energy
is not limiting, a curvilinear response in diets in
which energy is limiting. He also attributed the

diminishing response per unit of protein to the
use of protein as a source of energy. Winchester
and Harvey (1966) reported three-dimensional
diagrams of a similar type. Ørskov and McDo-
ald (1979) and Ørskov (1982) reported that
degradability over time of CP both in the
rumen and in nylon bags was best described by
an exponential equation.

The fact that DE was not as highly corre-
lated to NR \((R = .25)\) as DN to NR \((R = .72)\)
suggests that DE and DN are influenced by
different chemical and physiological factors and
perhaps by the site of digestion. No regression
equations derived from data of this study
reliably predicted DE from CP content of
forage. Other data from this laboratory indi-
cate that NR by steers may be increased when
forage diets of high CP content are supplemented
with DE in the form of cracked corn (Fischer et
al., 1985). Owens and Zinn (1982) have postu-
lated that the influence of diet on rate of CP
digestion in forages may be attributed to
association of CP with fiber and to different
rates of fiber digestion. Data obtained from this
study indicate that DE and the curvilinearity of
the relationships of CP to DN and NR are
important predictor variables. These predictive
equations represent the response in increments
of protein in forage diets in which energy may
be limiting at higher levels of CP intake. Thus,
the regression equation obtained in this study
should not be extrapolated to forage diets with
extensive supplementation with grains and(or)
other concentrate materials high in DE.

Nitrogen Retention. Nitrogen retention
expressed as a percentage of total N consumed
\((NR)\) is indicative of the total usefulness of N in
the diet in maintaining the body of the animal
as measured in this study. These data do not
explain the magnitude of the many facets of N
metabolism occurring in the body tissue and in
the gastrointestinal tract.

No significant prediction equations were
found for predicting NR from data obtained on
corn silage, cereal silages, or alfalfa hays. This
may have been due to the small number of
observations involved or to factors not included
in this study. The most accurate prediction
equations for NR by steers fed sorghum silages
was equation number 21 of table 4. It involved
the curvilinear relationship of NR to CP and to
DE content of the hays as predictor variables.
However, the standard error of the mean \( (s_{y.x}) \)
was 20.62, which was very high. Eliminating
DE as a variable and retaining the curvilinear
## Table 4. The Best Prediction Equation for Nitrogen Retention as a Percentage of Nitrogen Intake for Each Forage Type Studied

<table>
<thead>
<tr>
<th>Forage</th>
<th>Equation</th>
<th>No. of forages</th>
<th>DE level&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Equation&lt;sup&gt;b&lt;/sup&gt;</th>
<th>R&lt;sup&gt;2&lt;/sup&gt;</th>
<th>s&lt;sub&gt;y.x&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sorghum silage</td>
<td>20</td>
<td>20</td>
<td></td>
<td>NR(%) = -122.3284 + 21.5078(%CP) - .8824(%CP)&lt;sup&gt;2&lt;/sup&gt;</td>
<td>.43**</td>
<td>20.87</td>
</tr>
<tr>
<td></td>
<td>21</td>
<td>20</td>
<td></td>
<td>NR(%) = -158.5905 + 18.4841(%CP) - .7225(%CP)&lt;sup&gt;2&lt;/sup&gt; + 19.5356(DE)</td>
<td>.48*</td>
<td>20.62</td>
</tr>
<tr>
<td>Legume hays</td>
<td>22</td>
<td>17</td>
<td></td>
<td>NR(%) = -31.0438 + 5.7297(%CP) - .1471(%CP)&lt;sup&gt;2&lt;/sup&gt;</td>
<td>.64**</td>
<td>6.41</td>
</tr>
<tr>
<td></td>
<td>23</td>
<td>17</td>
<td></td>
<td>NR(%) = -103.3993 + 8.2973(%CP) + 42.9523(DE) + .0155(%CP)&lt;sup&gt;2&lt;/sup&gt; + 3.6818(DE)&lt;sup&gt;2&lt;/sup&gt; - 3.5172(%CP)(DE)</td>
<td>.72**</td>
<td>6.35</td>
</tr>
<tr>
<td>Sorghum sudan</td>
<td>24</td>
<td>13</td>
<td></td>
<td>NR(%) = -93.5439 + 16.1999(%CP) - .5314(%CP)&lt;sup&gt;2&lt;/sup&gt;</td>
<td>.47*</td>
<td>6.75</td>
</tr>
<tr>
<td>Temperate grasses hays</td>
<td>25</td>
<td>17</td>
<td></td>
<td>NR(%) = -173.9080 + 2.4590(%CP) + 56.8190(DE)</td>
<td>.86***</td>
<td>7.74</td>
</tr>
<tr>
<td>Plains bluestem hays</td>
<td>26</td>
<td>12</td>
<td></td>
<td>NR(%) = -1158.6035 + 2.3662(%CP) + 763.6557(DE) - 126.0908(DE)&lt;sup&gt;2&lt;/sup&gt;</td>
<td>.62*</td>
<td>7.84</td>
</tr>
<tr>
<td>Bermudagrass hays</td>
<td>27</td>
<td>37</td>
<td></td>
<td>NR(%) = -68.5228 + 10.9967(%CP) - .32297(%CP)&lt;sup&gt;2&lt;/sup&gt;</td>
<td>.39***</td>
<td>12.06</td>
</tr>
<tr>
<td></td>
<td>28a</td>
<td>10</td>
<td>1</td>
<td>NR(%) = -29.6602 + 3.7359(%CP) + .00506(%CP)&lt;sup&gt;2&lt;/sup&gt;</td>
<td>.53&lt;sup&gt;d&lt;/sup&gt;</td>
<td>10.45&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>28b</td>
<td>20</td>
<td>2</td>
<td>NR(%) = -42.7903 + 9.0641(%CP) - .30146(%CP)&lt;sup&gt;2&lt;/sup&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>28c</td>
<td>7</td>
<td>3</td>
<td>NR(%) = -166.3432 + 19.0551(%CP) - .47388(%CP)&lt;sup&gt;2&lt;/sup&gt;</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup>1 = <2.42 Mcal/kg, 2 = 2.42 to 2.87 Mcal/kg, 3 = >2.87 Mcal/kg.

<sup>b</sup>NR = Nitrogen retention expressed as a percentage of that consumed by steers in metabolism trials; CP = crude protein in forage calculated as N x 6.25; DE = digestible energy (Mcal/kg) as determined in digestion trials.

<sup>c</sup>Standard error of the mean.

<sup>d</sup>Values for R<sup>2</sup> and s<sub>y.x</sub> when equations 28a, 28b and 28c are used to predict NR(%) at three levels of DE.

*P < .05.

**P < .01.

***P < .001.
relationship of NR to CP (equation 20) was associated with $s_{y.x}$ of 20.87. This high $s_{y.x}$ indicates that these predictive equations for NR in steers fed sorghum silage are of limited value. Two predictive equations for NR in steers fed legume hays are in Table 4. Equation 23 was associated with the largest $R^2$ and lowest $s_{y.x}$. It included the curvilinear relationship of NR to both CP and DE content of the hays and the interaction between these predictor variables. Using only the curvilinear relationship of NR to CP (equation 22) resulted in a slightly lower $R^2$ value and slightly lower $s_{y.x}$. Both of these equations should be useful in predicting NR by steers on diets containing large amounts of legume hay. Energy did not appear to play a significant role in NR retention by steers fed legume hays. Equation 24 containing the curvilinear relationship of NR to CP was the best predictive equation when sorghum-sudan hay was fed.

The best predictive equation for NR by steers fed temperate grasses was the equation

$$-163.9086 + 2.459(\%CP) + 56.8190(\%DE), R^2 = .86$$

and $s_{y.x} = 7.74$. Thus, in tall fescue, prairie grass, brome and plains bluestem hays, both CP and DE were important predictor variables. The plains bluestem hays, since they are summer perennials, were analyzed separately. Equation 26, which included the curvilinear relationship of NR to CP and DE as predictor variables, was best. The high $R^2$ value of .62 and $s_{y.x}$ value of 7.84 may be compared with the equation

$$NR(\%) = -96.2193 + 38.8952(\%DE),$$

which had a $R^2$ value of .50 and $s_{y.x}$ of 8.10. Thus, NR by steers fed plains bluestem hay reacted positively to DE content.

The best equations for predicting NR in steers fed bermudagrass hays were 28a, 28b and 28c where the curvilinear relationship of NR to CP was calculated for each level of DE studied. The combination of predicted values for the three equations gave a $R^2$ value of .53 and $s_{y.x}$ of 10.45. Equation 26, involving the curvilinear relationship of NR to CP, was less accurate ($R^2 = .39$ and $s_{y.x} = 12.06$). The equation

$$NR(\%) = -23.9323 + 3.3680(\%CP) - 1.3278(\%DE)$$

had a $R^2$ value of .33 and $s_{y.x}$ of 16.00. Thus, the curvilinear relationship of NR to CP was significantly different at the levels of DE designated in this study.

The best predictive equation for NR by steers from analysis of pooled data on 116 forages studied are in Table 5. Equation 29, involving only the curvilinear relationship of
NR to CP, had a R² value of .40 (P<.01) and sₓₓ of 14.91. Formulating equations incorporating this predictor value for DE levels of <2.42 Mcal/kg (equation 30a), 2.42 to 2.87 Mcal/kg (equation 30b) and >2.87 Mcal/kg (equation 30c) resulted in R² of .42 (P<.001) and sₓₓ of 14.86. Equation 31 incorporated the curvilinear relationship of NR to both CP and DE, and the interaction between these predictor variables had a R² value of .42 (P<.001) and sₓₓ of 14.95. Thus, the curvilinear relationship of NR to CP appeared to be the major factor influencing NR. The addition of the three DE levels as variables resulted in only a slight improvement in R² (.40 to .42). The sₓₓ value of 14.86 of the combination of equations 30a, 30b and 30c was only slightly less than that for equation 29.

It is interesting to note that the best predictive equations for legume hays, sorghum-sudan hays, hays made from temperate grass hays, plains bluestem hays and bermudagrass hays were all associated with higher R² and lower sₓₓ values than any equation derived from pooled data. This indicated that, in case of these forage groups it would be more accurate to use predictive equations for each forage than one derived from pooled data. The equation NR(%) = -15.0270 + 1.9047(%CP) expressing the linear relationship of NR to CP in 116 forages had a R² of .23 and sₓₓ of 16.90. This confirms earlier observations that NR has a curvilinear relationship to CP. The results of this study also indicate that in some forage groups no useful predictive equations were found involving CP and DE as predictor variables for NR. Also, it should be pointed out that the mix of forages present in any body of pooled data can influence the predictive equations derived from statistical analyses of the data.

Literature Cited


