Effects of Supplementation on Voluntary Forage Intake, Diet Digestibility, and Animal Performance[1,2]

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ABSTRACT: A data base was constructed to describe and estimate supplementation effects in nonlactating cattle consuming forage ad libitum. The data base included 66 publications on 126 forages (73 harvested and 53 grazed) and a total of 444 comparisons between a control, unsupplemented treatment and a supplemented treatment. Daily gains were reported for 301 comparisons and voluntary intake for 258. Direct measures of forage digestibility were reported for 202 comparisons, and total diet digestibility for 150. Supplements did not increase gain in all cases. Change in ADG due to supplement was not related closely to intake of supplemental TDN. Lowest increases in ADG were with native forages supplemented with molasses alone or with low intakes of molasses containing high levels of NPN. Greatest increases in gain were with improved forages, supplements with > 60% TDN, and supplemental CP intake > .05% of BW. Supplements decreased voluntary forage intake (VFI) when supplemental TDN intake was > .7% of BW, forage TDN:CP ratio was < 7 (adequate N), or VFI when fed alone was > 1.75% of BW. When supplements increased VFI, forage TDN: CP ratio was > 7 (N deficit), and VFI when fed alone was often low. There was little relationship between change in VFI and sources of supplemental CP and TDN. Supplements caused total diet TDN concentration to deviate from expected values by –10 to +5% of OM. When supplemental TDN intake was > .7% of BW, diet TDN concentration was always less than expected. There was little relationship between deviation from expected total diet TDN and type or composition of forages or supplements. Empirical multiple regression equations were developed to estimate effects of supplements on VFI and total diet TDN concentration. The most acceptable intake equation estimated VFI when fed with supplement (r^2 = .84) That equation included VFI when fed alone, supplement intake, CP and TDN concentrations in forage and supplement, and classification codes describing forages and supplemental energy. The most acceptable equation for estimating total diet TDN concentration included only the expected total diet TDN concentration (r^2 = .87). These equations may be used in nutritional models to account for associative effects.

Key Words: Supplementary Feeds, Weight Gain, Forage, Diet

Introduction

When cattle consume forages as their only energy source, intake of available energy may not be adequate to meet desired rates of animal performance (i.e., ADG or milk production). In such cases, supplements may be provided to attain the desired performance. In many cases, animal responses to

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supplements are either greater or less than expected. The deviations between expected and observed performance are usually explained by associative effects of supplements upon voluntary intake and available energy concentration of the total diet. The concept of associative effects refers to nonadditive interactions among ingredients in mixed diets.

This paper focuses on associative effects that occur when forage intake is voluntary and supplements are fed separately in restricted amounts. Although associative effects under these conditions are well-documented, they are difficult to quantify and are not considered in most nutritional models. After an extensive review of associative effects in forage-based diets, Horn and McCollum (1987) concluded that “present relationships do not permit prediction of effects of supplementation on forage intake and utilization for the widely different production environments.” Their challenge is addressed in this article.

In most nutritional models, gain is a function of both intake and available energy concentration (e.g., TDN) of the total diet, and these are used independently in computations. Because, in the context of this article, supplement intake is known, supplement effects on voluntary forage intake may be quantified. It is not possible, however, to quantify the effect of supplement on the TDN concentration of the forage component of a mixed diet. Further, it is not known if the associative effect applies to the supplement as well as the forage. It is necessary, therefore, to compare the observed TDN of the total diet with that expected from the TDN of the ingredients (Brant, 1993).

The objectives of this review are to examine effects of supplements on daily gain, voluntary forage intake, and total diet TDN concentration and to develop and evaluate equations for estimating total diet intake and total diet TDN concentration.

Effects of Supplements on Gain, Intake, and TDN

Data base Construction. A literature review provided 66 references that met the requirements for inclusion in the data base (i.e., voluntary forage intake, supplements fed separately, nonlactating cattle, and an unsupplemented control treatment); these references are found in the Appendix. The 66 references included studies of 126 different forages: 73 harvested and 53 grazed. There were 444 comparisons of an unsupplemented control with a supplemented treatment. Table 1 summarizes the distribution of these comparisons among forages and supplements in the data base.

Most studies involved growing calves or yearlings. If cows were used in the study, intake and digestibility data were included, but their daily gains were not. If full body weights and gains were reported, they were converted to the shrunk basis using equations derived from full and shrunk weights on forage-fed cattle (Kunkle and Moore, unpublished data). Intake data were converted to a percentage of mean shrunk body weight.

Data on forage characteristics were limited to those provided in the references. Digestibility data used in the data base were limited to those from in vivo trials.

Table 1. Distribution of comparisons between unsupplemented and supplemented treatments (444 total comparisons)

By forage type	n	By supplement type	n
Temperate	122	Liquid	150
Tropical	125	Dry	255
Native	175	Combined	39
Straw	22		
By sources of supplemental energy and protein			
Energy	n	Protein	n
Protein feeds only	43	Energy feeds only	148
Molasses	178	Non-protein nitrogen	142
Grain	129	Protein feeds	143
By-Products	35	Combinations (NPN + feeds)	11
Forages	27		
Combinations	32		

In some cases, digestion trials were conducted with sheep and these data were used without adjustment. Data on DM digestibility of forages and mixed diets were converted to OM digestibility by the following formula (Moore, unpublished data): OM digestibility (%) = –.664 + 1.032 × DM digestibility (%). Forage TDN was assumed to be equivalent to digestible OM.

Regarding supplements, composition data were taken from the reference, or calculated from supplement ingredient formulas, as given in the reference, and tabulated values of CP and TDN concentration. Because of the wide variation in ash percentage reported for many forages and supplements, all data were converted to the OM basis by dividing concentrations on the DM basis by the OM concentration as a percentage of DM.

Effects on Daily Gain. Associative effects between supplements and forages were demonstrated clearly in terms of ADG. In many cases, ADG was not increased when forages were supplemented, and was sometimes decreased (Figure 1). Effects of supplements on ADG were quantified as the change in shrunk ADG (GAINchg), using the following formula: GAINchg = GAINtotal – GAINforage, where GAINtotal = shrunk ADG on total mixed diet (kg/d) and GAINforage = shrunk ADG on forage fed alone (kg/d). A positive GAINchg indicates that ADG was increased when supplements were fed. Most, but not all, GAINchg values were positive.

Forage and supplement types were confounded when GAINchg was at either extreme (Table 2). Decreases and slight increases (< .02 kg/d) in daily gain occurred primarily with grazed native forages supplemented with molasses alone or molasses with NPN. When GAINchg was greatest(> .4 kg/d), however, it occurred with harvested improved forages that were supplemented with either dry feeds or molasses with added nitrogen. At intermediate ranges of GAINchg, there was little difference among types of forages and supplements with respect to GAINchg.

There was little relationship between GAINchg and supplemental TDN intake (STDNI) (Figure 2). At

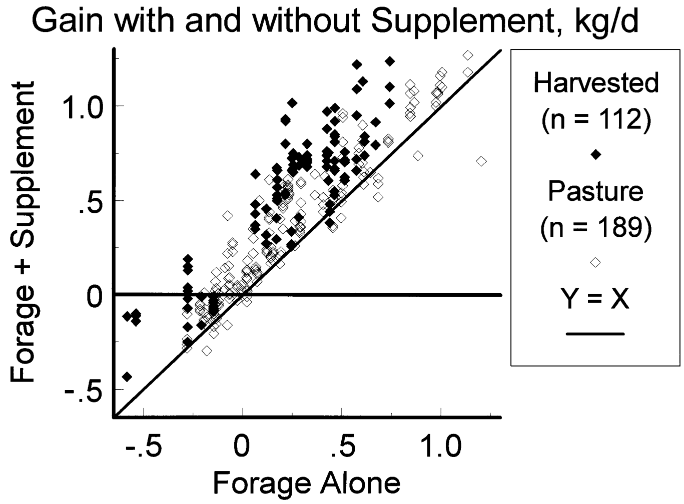

Figure 1. Comparison of daily gain by cattle when fed forage plus supplement with daily gain when the same forage was fed alone.

Table 2. Frequency distribution of forages and supplements according to ranges of change in daily gain due to supplements

	Range in gain change due to supplementation, kg/d						
Comparison	< .02	.02 to .05	.06 to .10	.11 to .20	.21 to .30	.31 to .40	>.40
Total	29	33	57	61	42	41	38
Forages							
Grazed	27	28	46	41	29	13	5
Harvested	2	5	11	20	13	18	33
Native+straw	18	26	36	30	3	3	4
Cool+warm	11	7	21	31	38	38	34
Supplements							
Molasses	25	28	37	34	17	15	13
Alone	11	9	6	5	0	2	0
+NPN	14	18	21	29	13	4	5
+Meal	0	0	0	0	3	4	5
+NPN+meal	0	1	0	0	1	5	3
Dry feeds	4	5	20	27	25	26	25

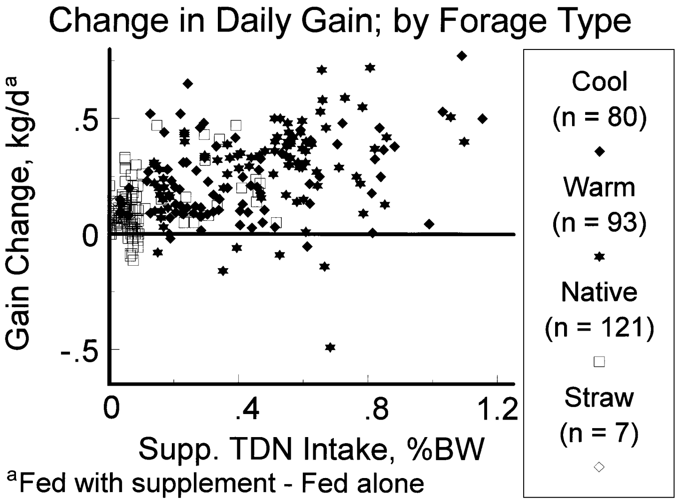

Figure 2. Effect of supplemental total digestible nutrient (TDN) intake on change in daily gain due to supplement, classified by type of forage.

low STDNI, there was often a large positive GAINchg, especially with native forages. Negative GAINchg occurred in a few cases with native forages and warm-season improved forages. The same array of data classified according to energy source (Figure 3) illustrates the confounded nature of the data base discussed above (e.g., native forages were supplemented often with molasses). Also, most of the

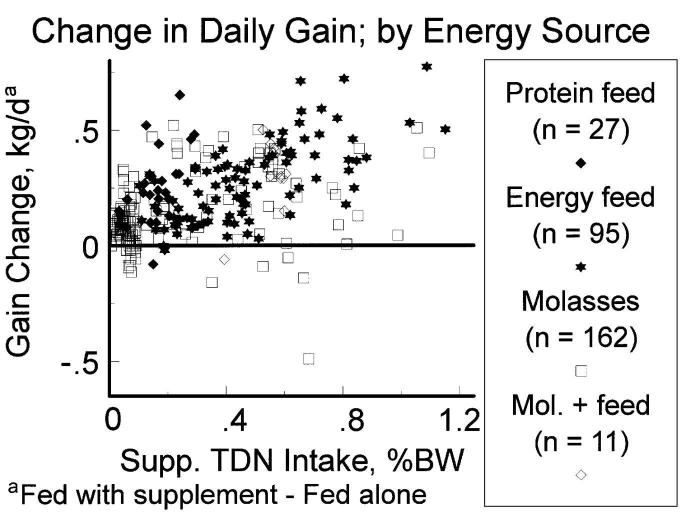

Figure 3. Effect of supplemental total digestible nutrient (TDN) intake on change in daily gain due to supplement, classified by source of supplemental energy.

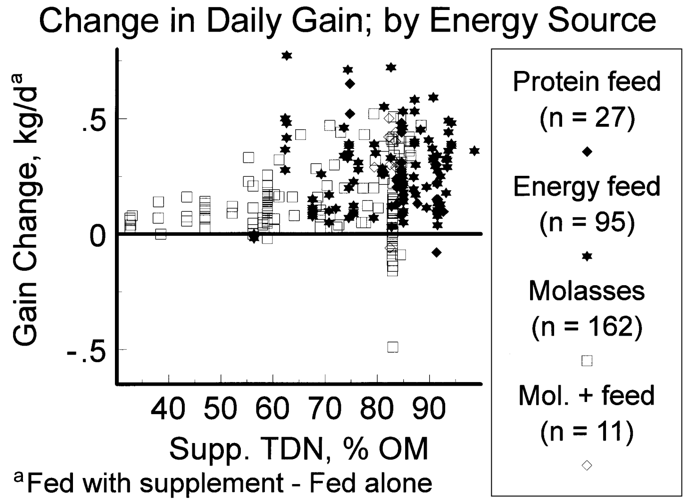

Figure 4. Effect of supplemental total digestible nutrient (TDN) concentration on change in daily gain due to supplement, classified by source of supplemental energy.

negative GAINchg values were with molasses having a high TDN percentage (Figure 4); these supplements contained nonprotein nitrogen (NPN) sources such as urea and ammonium sulfate (Figure 5).

In many cases, the TDN concentration of molasses supplements was less than 60% of OM (Figure 4); these supplements contained high percentages of NPN

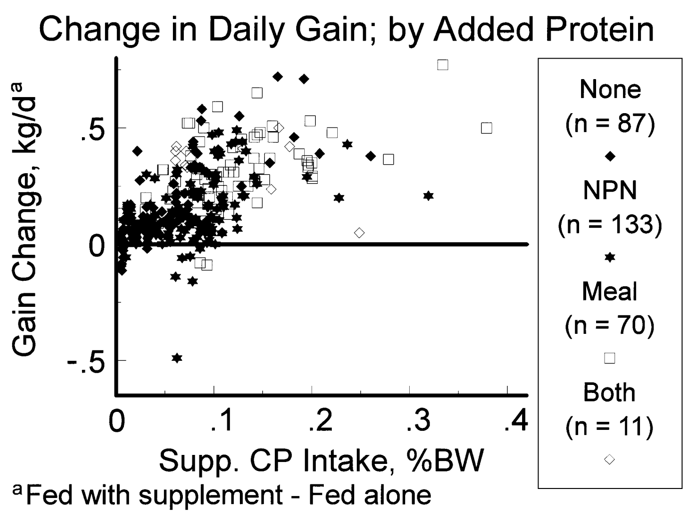

Figure 5. Effect of supplemental crude protein (CP) intake on change in daily gain due to supplement, classified by source of added supplemental protein (in addition to protein from energy feeds, if any).

because molasses was used simply as a carrier. Generally, these supplements were fed in small amounts and gave a positive but relatively small GAINchg. When supplemental TDN percentage was above 60% of OM and GAINchg was positive, GAINchg was not related to energy source.

The largest increases in GAINchg occurred when supplemental CP intake was greater than .05% of BW (Figure 5). When supplemental CP intake was greater than .1% of BW, GAINchg was always positive. There was little difference among sources of protein. Low GAINchg values were observed at low CP intakes, but this effect is confounded with type of forage and supplement (low GAINchg with native pastures supplemented with molasses and NPN). When responses to feed protein supplements were examined (Figure 6), there was little difference among grains, by-products, and plant protein feeds, but supplements with added escape protein tended to give the highest GAINchg at a given STDNI.

Effects on Voluntary Forage Intake. Voluntary intake of forage was both increased and decreased by supplementation (Figure 7). Most of the increases were with native forages and straws, whereas most of the decreases were with improved cool and warm season forages. When forage intake fed alone was > 1.75% of BW, supplement decreased forage intake in most cases.

Effects of supplements on voluntary forage intake were quantified as the change in VFI, as a percentage of body weight (VFIchg), using the following formula: VFIchg = VFIwith − VFIalone, where VFIwith = VFI of forage fed with supplement (% of BW, OM basis) and VFIalone = VFI of forage fed alone (% of BW, OM basis). A negative VFIchg means that supplement decreased intake of the forage. This effect has been termed substitution (i.e., supplement substitutes for forage) and has been expressed as substitution rate, the decrease in VFI per unit of supplement fed. The use of VFIchg provides a more readily understood expression of the effect of supplements on forage intake; it is negative when intake is decreased, and positive when intake is increased.

When VFIchg was compared with the ratio of TDN to CP in forages (FTDN:CP; Figure 8), it appeared that much of the effect due to forage type could be explained by this characteristic of the forage. When FTDN:CP was < 7, VFIchg was generally negative. The straws that accounted for five of the seven exceptions (i.e., positive VFIchg when FTDN:CP was < 7) were ammoniated. When FTDN:CP was > 12, almost all VFIchg were positive, and all forages were native. When VFIchg was compared with STDNI and responses classified by FTDN:CP (Figure 9), increasing STDNI resulted in a more negative VFIchg with forages having FTDN:CP < 7. There was little effect of STDNI on VFIchg with those forages having FTDN: CP > 7, except when STDNI was greater than .7% of BW. In almost all comparisons, except for ammoniated straws, when VFIchg was positive, FTDN:CP was > 7.

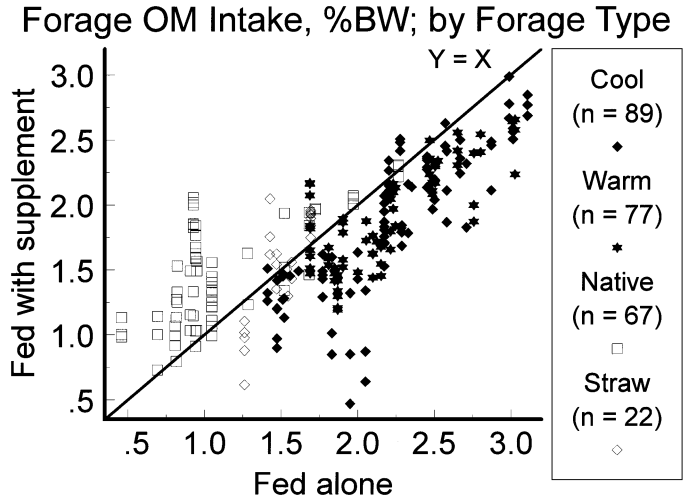

Figure 7. Comparison of voluntary forage organic matter (OM) intake when fed with supplement to intake when the same forage was fed alone, classified by type of forage.

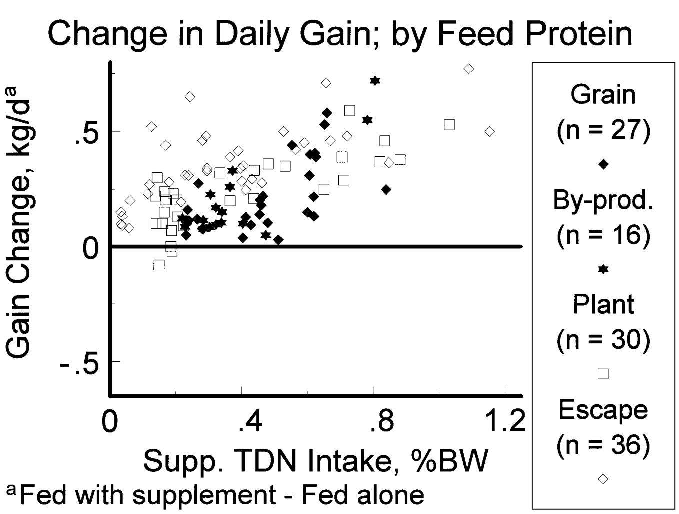

Figure 6. Effect of supplemental total digestible nutrient (TDN) intake on change in daily gain due to supplement, classified by source of feed protein (does not include non-protein nitrogen sources).

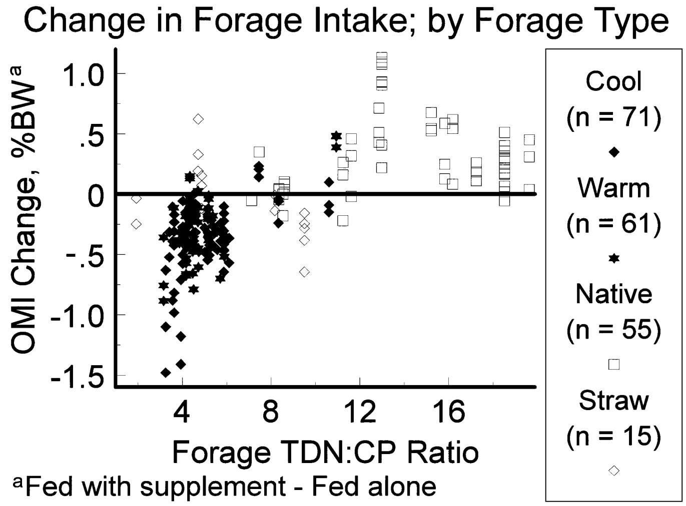

Figure 8. Effect of the ratio between forage total digestible nutrient (TDN) concentration and crude protein concentration (CP) on the change in voluntary forage organic matter intake (OMI) due to supplementation, classified by type of forage.

Perhaps FTDN:CP values greater than 7 indicate a deficit of N in relation to available energy.

There was no clear distinction among energy sources with respect to the effect of STDNI on VFIchg (Figure 10), except that protein feeds generally gave a negative VFIchg. When VFIchg was positive, there was no difference in response between liquid and dry supplements. When STDNI was > .7% of BW, VFIchg was always negative. There was no apparent relationship between supplemental CP intake and VFIchg, and no apparent difference in response among sources of added protein (Figure 11). When VFIchg was positive, NPN and meal were equally effective.

Effects on Dietary TDN. The TDN concentration of total diets was both greater and less than expected (Figure 12). Expected total diet TDN was calculated as follows: TDNexpected (% of OM) = [(VFIwith × FTDN) + (SOMI × STDN)]/(VFIwith + SOMI), where VFIwith is as defined above, FTDN = forage TDN (% of OM), SOMI = supplement OM intake (% of BW), and STDN = supplement TDN (% of OM). When expected TDN was greater than 60% of OM, the observed TDN was less than expected in most cases.

Effects of supplementation on total diet TDN concentration were quantified as deviation from expected total diet TDN (TDNdev), calculated as follows: TDNdev = TDNobserved – TDNexpected, where TDNobserved = observed TDN of total diet (% of OM) and TDNexpected is as defined above. A negative TDNdev indicates simply that supplementation resulted in an observed total diet TDN concentration that was less than expected. It does not indicate whether supplement altered the digestibility of the forage, the supplement, or both.

There was a large range in TDNdev (Figure 13), with many values between –10 and +5% of OM (not TDN). Such large deviations from expected TDN

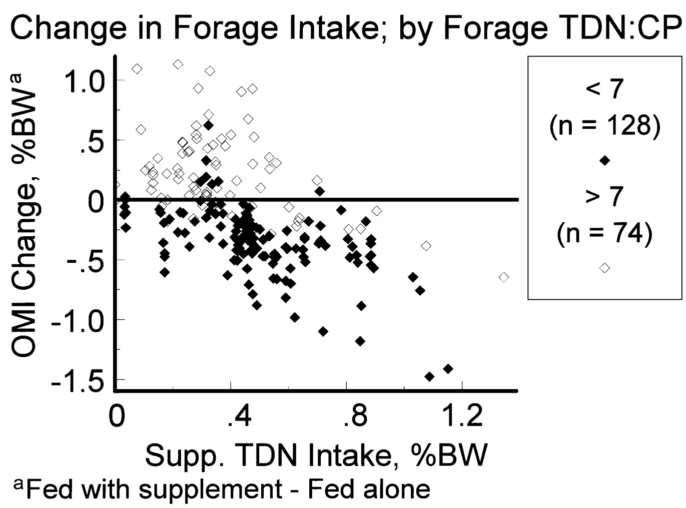

Figure 9. Effect of supplemental total digestible nutrient (TDN) intake on the change in voluntary forage organic matter intake (OMI), classified by forage TDN: crude protein (CP) ratio.

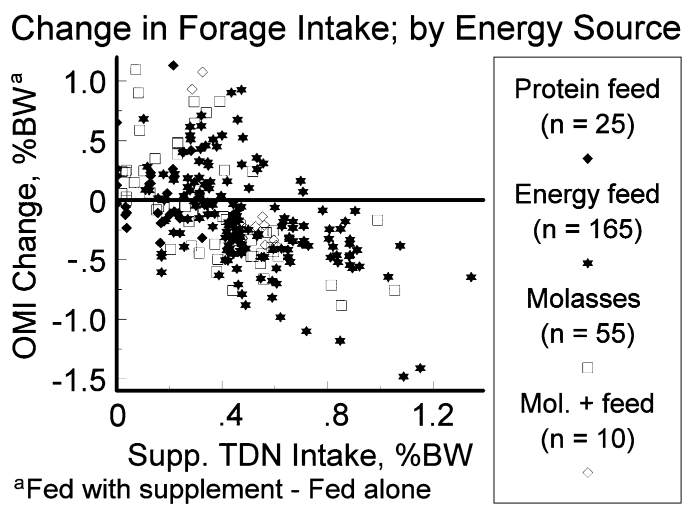

Figure 10. Effect of supplemental total digestible nutrient (TDN) intake on the change in voluntary forage organic matter intake (OMI), classified by source of supplemental energy.

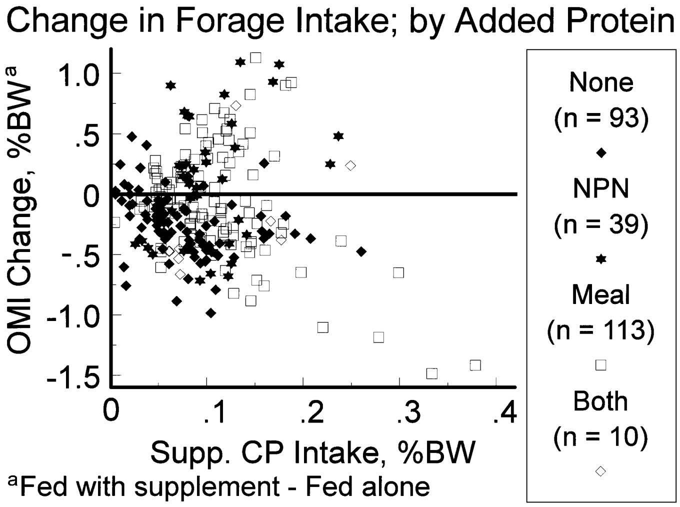

Figure 11. Effect of supplemental crude protein (CP) intake on the change in voluntary forage organic matter intake (OMI), classified by source of added supplemental protein (in addition to protein from energy feeds, if any).

concentrations would have major effects on the NE concentration of diets, and on estimated animal performance. In most cases when TDNdev was positive, the forage was a native hay or straw having a TDN concentration < 55% of OM. When STDNI was greater than .7% of BW, TDNdev was negative in most cases (Figure 14). There was little difference among energy sources with respect to TDNdev.

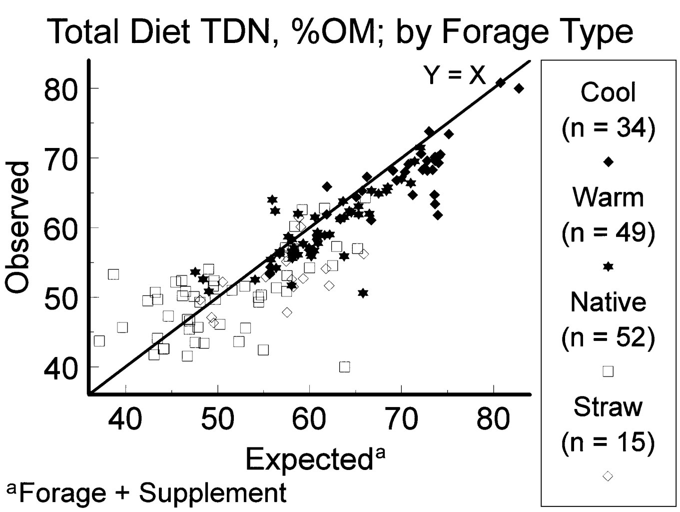

Figure 12. Comparison of observed to expected total digestible nutrient (TDN) concentration in total diets (forage plus supplement), classified by type of forage.

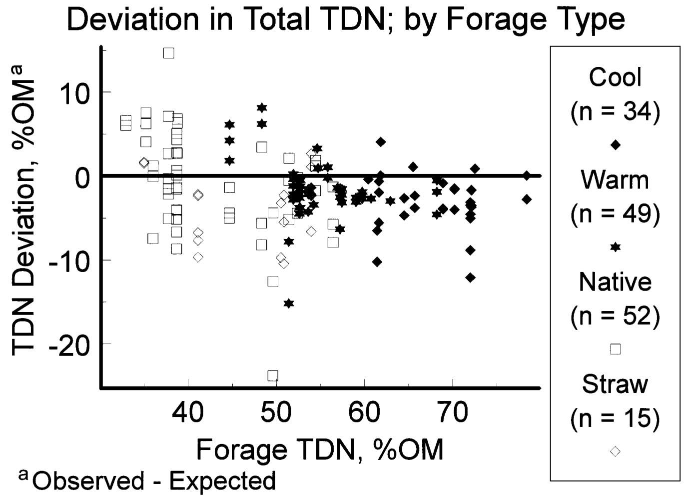

Figure 13. Effect of forage total digestible nutrient (TDN) concentration on the deviation from expected total diet TDN concentration, classified by type of forage.

Development and Evaluation of Equations

The data base was divided into two subsets: one for equation development and the other for equation evaluation. The development subset was used to select variables and generate coefficients for the estimation of total diet intake and TDN concentration. The evaluation subset was used as an independent data

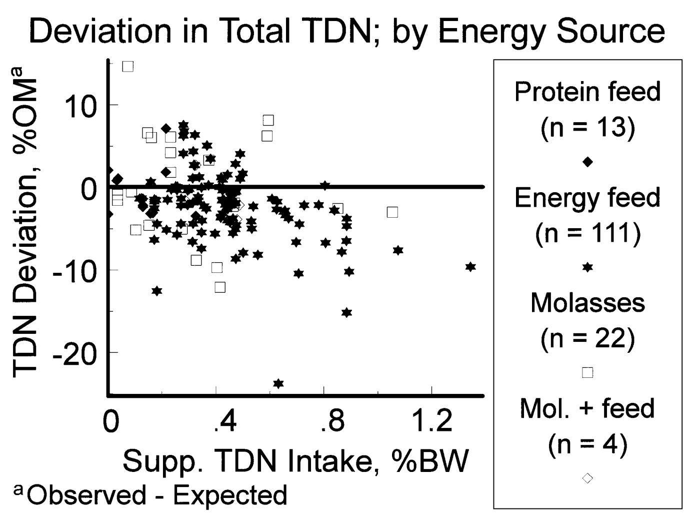

Figure 14. Effect of supplemental total digestible nutrient (TDN) intake on the deviation from expected total diet TDN concentration, classified by source of supplemental energy.

set to evaluate equations. About 25% of the total comparisons were assigned to the evaluation subset. A particular reference was assigned to either one subset or the other. Attempts were made to have each subset similar with respect to distributions of forages and means of forage and supplement variables (Table 3). The range in variables was narrower in the evaluation subsets than it was in the comparable development subsets. When forage TDN was included in the intake subsets, the number of comparisons was decreased in the development subset more than it was in the evaluation subset.

Equations were developed using the appropriate development data sets. Independent variables (X) included VFIalone, forage CP (% of OM), forage TDN (% of OM), forage TDN:CP ratio, supplement OM intake (% of BW), supplement CP (% of OM), and supplement TDN (% of OM). All independent variables were squared, and several products were calculated (e.g., supplement TDN intake, % of BW). In addition, many linear interactions among forage and supplement variables were calculated (e.g., forage TDN × supplement TDN). Classification codes describing types of forages and supplements were included as independent variables; these are defined in the following.

Forage type codes:

1 = temperate or tropical forage
2 = native mixed forage, or straw

Supplement type codes:

1 = dry
2 = liquid (e.g., based on molasses)
3 = combination (e.g., slurry)

Supplemental energy codes:

1 = protein supplement only (e.g., soybean meal)
2 = molasses
3 = grain or by-product (e.g., corn, wheat middlings)
4 = forage (e.g., alfalfa)

Supplemental carbohydrate degradability codes:

0 = rapid (e.g., corn)
1 = slow (e.g, soybean hulls)

Supplemental protein codes:

1 = energy feed (e.g., corn)
2 = non-protein nitrogen (e.g., urea)

Table 3. Description of data subsets used in development and evaluation of equations to estimate organic matter intake (% of body weight) and total digestible nutrient concentration (% of organic matter) of total diets

	Intake subsets				TDN subsets	
	Ignoring forage TDN		Including forage TDN			
Item	Develop	Evaluate	Develop	Evaluate	Develop	Evaluate
References, n	31	15	24	15	23	9
Comparisons, n	187	59	144	56	111	37
Temperate	68	18	56	15	26	8
Tropical	56	21	40	21	36	13
Native	48	16	38	16	35	16
Straw	187	4	10	4	14	0
Forages						
OM intake, % BW	1.87 ± .64	1.83 ± .62	1.85 ± .66	1.80 ± .61	1.87 ± .77	1.82 ± .50
CP, % OM	10.2 ± 5.6	9.1 ± 4.3	10.4 ± 5.8	9.2 ± 4.4	9.7 ± 5.9	8.3 ± 3.4
TDN, % OM			55.1 ± 12.2	51.9 ± 8.9	52.8 ± 12.2	52.2 ± 8.1
Supplements						
OM intake, % BW	.53 ± .31	.51 ± .28	.56 ± .32	.52 ± .28	.51 ± .28	.47 ± .27
CP, % OM	23.0 ± 22.3	23.2 ± 18.8	19.8 ± 12.9	21.9 ± 18.5	21.0 ± 15.8	21.4 ± 16.3
TDN, % OM	81.3 ± 10.7	83.5 ± 7.9	82.1 ± 10.0	83.5 ± 8.1	80.6 ± 9.2	85.0 ± 8.4
Total diets						
OM intake, % BW	2.25 ± .47	2.29 ± .54	2.23 ± .50	2.27 ± .54	2.32 ± .57	2.28 ± .44
TDN, % OM						
Observed					57.3 ± 9.0	57.3 ± 6.6
Expected					59.4 ± 10.1	58.9 ± 7.8

3 = protein feed (e.g, soybean meal, meat meal)
4 = combination of NPN and feed

Supplemental protein degradability codes:

0 = ruminally degraded (e.g., urea, soybean meal)
1 = escape (e.g., fish meal, meat meal)

General relationships between dependent and independent variables (including squares, products, and interactions) were explored using PROC REG of SAS with stepwise selection at $P < .15$. Many combinations of independent variables were examined to determine which variables were most often included. Final selection of variables was done using the R^2 selection with the C_P statistic to minimize bias and avoid overfitting (MacNeil, 1983). In no case was the correlation between interaction variables permitted to exceed .7. Independent variables were tested in various combinations. The final selection of variables was made from a set that included variables that had appeared frequently in previous runs. In this procedure, the combinations of variables tested are selected by the researcher rather than the computer.

After deciding which variables to include, coefficients for multiple regression equations were computed using PROC REG. Linear variables were added to the model if they occurred as squared terms or in interactions. These equations were then used to estimate intake or TDN variables for each comparison in the appropriate evaluation subset. Equations were evaluated by regressing observed values of dependent variables (Y) on the comparable estimate (X) and recording the coefficient of determination (r^2) and root mean square error (RMSE).

The major criterion used to evaluate equations was the difference between estimated and observed values (difference = estimated − observed). A negative difference indicates that the estimate was less than the observed value. The following criteria of acceptability of differences were based on common assumptions about the variability among animals fed alike for intake (10%) and digestibility (5%).

Mean total OM intake = 2.3% of BW

acceptable difference = 2.3 × .1 = .23
marginal difference = 2.3 × .2 = .46
unacceptable difference > .46

Mean total diet TDN = 57% of OM

acceptable difference = 57 × .05 = 2.9
marginal difference = 57 × .1 = 5.7
unacceptable difference > 5.7

Equations were evaluated on the basis of the percentage of differences that were acceptable, marginal, or unacceptable.

Intake Equations. There were three approaches to computing estimated total diet OM intake (ETOMI, % of BW):

1. VFIchg was estimated and ETOMI = VFIalone + estimated VFIchg + supplement OM intake.
2. VFIwith was estimated and ETOMI = estimated VFIwith + supplement OM intake.
3. ETOMI was estimated directly.

Some equations were developed using the entire development set. In addition, the development subset was divided into two additional subsets having forage TDN:CP ratios either above or below 7. Equations based on the entire data set were more acceptable than those based on the two subsets. The code for forage type was included in most equations, and this variable may have accounted for differences associated with forage TDN:CP ratio.

There were high correlations between forage CP concentration and forage TDN:CP, and between supplement OM intake and TDN intake. Therefore, in the final stages of equation development, either forage CP or forage TDN:CP ratio, and either supplement OM intake or TDN intake, were used in a 2 × 2 factorial arrangement. In all, 47 intake equations were developed. Each equation was evaluated by regressing observed or actual TOMI on ETOMI, the latter being calculated as described above for the three approaches.

The three best equations for each option gave very similar statistical parameters and differences between observed and estimated values (Table 4), but the VFIchg and VFIwith equations were slightly superior in terms of the difference criteria. In fact, the same variables were included in the VFIchg and VFIwith equations, even though they were developed independently. All coefficients were identical in the two equations, except for the coefficient for VFIalone. The coefficients for VFIalone were .0101 for the VFIchg equation and 1.0101 for the VFIwith equation; such a difference would be expected because VFIchg is calculated as the difference between VFIalone and VFIwith. Because it would be the simplest equation to use in nutritional computations, the VFIwith equation was chosen as the “best” equation, instead of the VFIchg equation; it is as follows:

Table 4. Evaluation of equations for estimating total diet organic matter intake and TDN concentration

Item	Intake, % of BW			TDN, % of OM	
	Change	With supp.	Total	Complex	Simple
Variables	15	15	13	7	2
Develop R^2	.86	.90	.88	.84	.77
Evaluate r^2	.84	.84	.82	.78	.87
RMSE[a]	.22	.22	.23	3.2	2.4
Difference[b]					
Mean	–.07	–.07	–.07	–1.0	–.9
±SD	.23	.23	.24	3.2	2.4
Percentage					
Acceptable	67.9	67.9	66.1	64.9	75.7
Marginal	30.3	30.3	30.3	24.3	21.6
Unacceptable	1.8	1.8	3.6	10.8	2.7

[a]Root mean square error.
[b]Difference = estimate – observed.

Estimated forage OM intake with supplement = –1.9875

+ 1.0101 × VFIalone
+ .0587 × $(\text{VFIalone})^2$
– .0195 × forage CP concentration
– .0408 × forage TDN concentration
– .911 × supplement TDN intake
+ .0204 × supplement CP concentration
+ .0699 × supplement TDN concentration
– .000569 × $(\text{supplement TDN concentration})^2$
+ 5.87 × supplement CP intake
– 9.74 × $(\text{supplement CP intake})^2$
– .221 × VFIalone × supplement TDN intake
– .0143 × VFIalone × supplement CP concentration
+ .000509 × forage TDN × supplement TDN
+ .211 × forage type code
– .0638 × supplemental energy code

Intake values are OM as % of BW and concentration variables are as % of OM.

As mentioned above, all intake equations were evaluated relative to total OM intake. The regression of observed on estimated total diet OM intake is plotted in Figure 15. Even though the forage type code was included, there appeared to be a discrepancy related to forage type. Intake of diets containing cool and warm season forages was often underestimated, and intake of diets containing native forages and straws was often overestimated. Nevertheless, 68% of estimates were acceptable, and only 2% (one comparison) was unacceptable (Table 4).

TDN Equations. There were two approaches taken for calculating estimated total diet TDN (ETTDN, % of OM): 1) TDNdev was estimated and ETTDN = expected TDN + estimated TDNdev and 2) ETTDN was estimated directly and expected TDN was an input variable. The first approach, estimating TDNdev, was not successful because all equations were unacceptable by all criteria. The second approach, estimating total TDN directly, gave 15 equa-

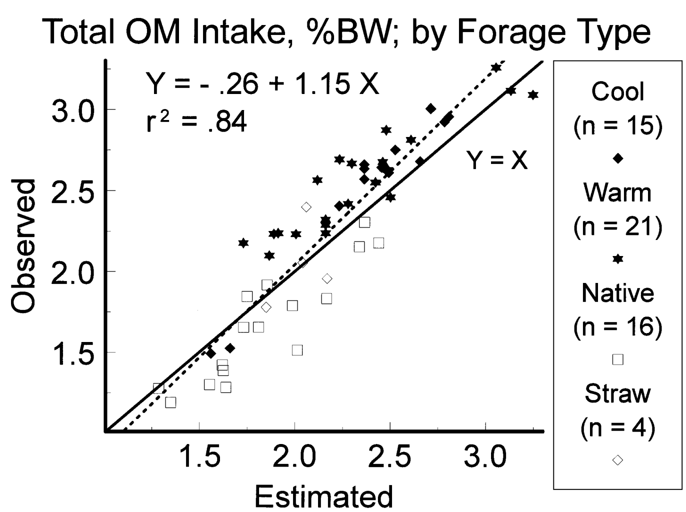

Figure 15. Regression of observed on estimated total diet organic matter (OM) intake with the evaluation data set, classified by type of forage.

tions that were evaluated by regressing observed total diet TDN on estimated total diet TDN. Evaluations of two equations are shown in Table 4. The “complex” equation was the one that best fit the development set; it included the following variables: expected TDN concentration, (expected TDN)^2, forage TDN concentration, forage TDN × expected TDN, forage code, supplement type code, and energy code. The simple equation fit the evaluation set best and was as follows:

$$\text{Estimated total diet TDN} = 59.71 - .8948 \times \text{expected TDN concentration (\% of OM)} + .01399 \times (\text{expected TDN concentration})^2$$

The regression of observed on estimated total diet TDN is plotted in Figure 16. Based on the difference between observed and estimated diet TDN, 76% of estimates were acceptable and 3% (one comparison) were unacceptable (Table 4). The evaluation data subset was rather small (Table 3) and may not have represented all the sources of variation in total diet TDN that were present in the development data subset. This equation does, however, have application in accounting for at least part of the associative effects on digestibility that occur in mixed diets.

Limits of Input Variables. Equations presented here should be used with caution when input variables are outside the range of variables in the development data set. Those ranges are as follows:

Forage OM intake fed alone (% of BW): .46 to 3.11
Forage CP (% of OM): 2.1 to 23.0
Forage TDN (% of OM): 34.9 to 78.4
Supplement OM intake (% of BW): .04 to 1.85
Supplement CP (% of OM): 6.7 to 98.4
Supplement TDN (% of OM): 52.7 to 95.4

Summary

The data base constructed here provided ample evidence that associative effects in forage-based diets occur and are often important quantitatively. Also, the data base provided the opportunity to develop equations to account for these associative effects in nutritional models.

Effect of Supplements on ADG. Supplements generally but not always increased ADG. There was little relationship between supplemental TDN intake and the change in ADG due to supplement. In many cases, small amounts of supplemental TDN increased gains, especially with native forages and straws. The use of escape protein tended to give greater increases in gain

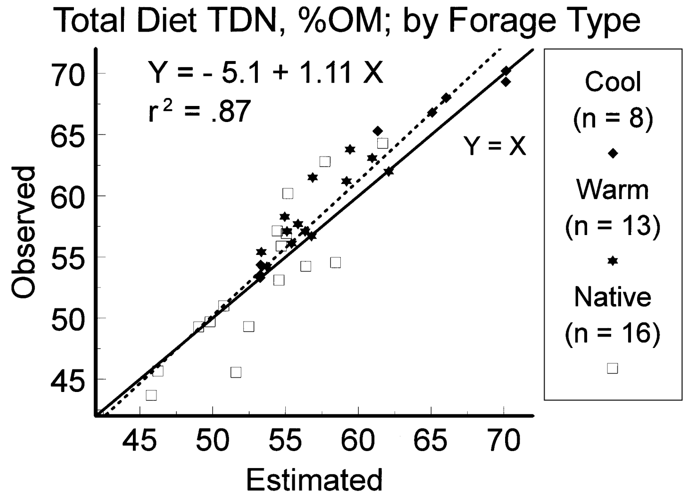

Figure 16. Regression of observed on estimated total digestible nutrient (TDN) concentration in the total diet (forage plus supplement) with the evaluation data set, classified by type of forage.

at a given intake of supplemental TDN than did other sources of protein. The least ADG response to supplement was seen with native forages supplemented with molasses alone or with low intakes of molasses containing high levels of NPN. The greatest response was seen with improved forages, when supplemental TDN was > 60% of OM (either dry feeds or molasses plus added protein), and when supplemental CP intake was > .05% of BW.

Effect of Supplements on Voluntary Forage Intake. The change in VFI due to supplement ranged from −1 to +1% of BW. Generally, supplements decreased intake with improved forages, but with native forages and straws, supplements both increased and decreased forage intake. This discrepancy may be related to the ratio of TDN to CP in forages, an indicator of the amount of N relative to available energy. When supplements increased forage intake, forage TDN:CP ratio was > 7 (deficit of N relative to available energy). Supplements decreased intake when the TDN:CP ratio was < 7 (adequate N) except for ammoniated straws, when forage intake fed alone was > 1.75% of BW, or when supplemental TDN intake was > .7% of BW. There was little difference between sources of supplemental CP or TDN relative to changes in forage intake. When forage intake was increased by supplement, liquid and dry feeds were equivalent as energy sources as long as the supplement contained added protein. As protein sources, NPN and protein meals were apparently equivalent for increasing intake.

Effect of Supplements on Total Diet TDN Concentration. When forages were supplemented, observed diet TDN deviated from expected TDN by –10 to +5% of OM. When diet TDN was greater than expected, the forage was a native hay or straw in most cases. When supplemental TDN intake was > .7% of BW, diet TDN was generally less than expected. There was little effect of type or composition of forages and supplements on the deviation from expected total diet TDN.

Equations to Estimate Forage Intake and Diet TDN in Mixed Diets. An acceptable equation to estimate voluntary forage intake when fed with supplement was developed. Inputs to the equation included voluntary forage intake when fed alone (a function of forage quality), supplement intake, forage and supplement CP and TDN concentrations, and codes describing forage types and supplemental energy sources. No attempt was made in this article to estimate voluntary forage intake when fed alone. An acceptable equation to estimate total diet TDN concentration was based on expected total diet TDN calculated from the weighted average of TDN concentrations in forages and supplements. The equations could be applied in two types of nutritional models: 1) in a static model to estimate animal response to a known quantity of supplement intake and 2) in an iterative model to compute the amount of supplement required to achieve a desired rate of animal performance. The equations should be used with caution outside the range of inputs in the data set used to develop them.

Implications

When forages are the only source of energy and protein for growing cattle, growth rates may be less than desired to meet production objectives. Supplements of energy and protein are often fed to increase growth rates, but the increase may be more or less than expected based on the amount and type of supplements fed. The deviations from expectations are due to interactions among forages and supplements that either increase or decrease forage consumption and availability of dietary energy. Several of the interactions that affect forage intake and diet available energy can be accounted for by equations based on common characteristics used to describe forages and supplements. Estimates of performance effects and economic consequences of supplementation strategies should be more accurate when these equations are included in nutritional models. Additional interactions among forages and supplements are likely, and further research is needed to elucidate and quantify them.

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