Alfalfa Hay Quality in Oregon

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ABSTRACT

New grading standards for hay have been proposed by the American Forage and Grassland Council and the Federal Grain Inspection Service. This publication traces the development of these standards, describes new terminology, and reports on research conducted at Oregon State University to evaluate these new standards.

Alfalfa hay samples obtained from five distinct geographical areas in Oregon were subjected to various chemical analyses (crude protein, neutral detergent fiber, acid detergent fiber, *in vitro* dry matter digestibility, calcium, and phosphorous). Differences between values for regions and cuttings were quite small, with mean values falling within the limits presently defined as Grade 2 alfalfa hay. This indicates that management factors are more important than geographical region or cutting in determining hay quality. These results also point out the importance of hay testing in providing an objective measure of hay quality.

Animal production studies also were conducted on alfalfa hays of varying quality. Acid detergent fiber was found to be a good predictor of both animal intake and digestibility. Milk production was greatest from cows fed rations containing high-quality hay when rations contained 45 percent hay, but no significant differences were observed when cows were fed rations containing only 30 percent hay.

DEVELOPMENT OF NEW HAY STANDARDS

The need for hay standards that precisely express forage feed value to hay producers, buyers, and agricultural scientists has long been recognized. Visual examination of hay by local buyers provides only an estimate of its feed value. Hay sold for long-distance transport to state, national, or international markets also would benefit from a standardized measure of forage feed value.

PROXIMATE ANALYSIS SYSTEM

Characterization of feed value by chemical analyses has historically involved the use of the Weende system of proximate analysis (Crampton and Harris, 1969). This system divides a feedstuff into six fractions: water, ether extract, crude fiber (CF), nitrogen-free extract (NFE), crude protein (CP), and ash. Five components are determined chemically while

NFE is determined by difference. Total feed carbohydrate is represented by the sum of CF and NFE.

With the proximate system, it is difficult to partition plant carbohydrates into CF and NFE. Plant fiber cannot be viewed simply as a chemically uniform substance because it includes cellulose, hemicellulose, lignin, and silica. In addition, crude fiber analysis allows a variable portion of the hemicellulose and lignin to be considered as NFE, which supposedly represents only available carbohydrate. The NFE is thus a mixture of all the starches and sugars of the sample, plus some hemicellulose and much of the lignin.

MODIFIED CRUDE FIBER (MCF)

In 1959, Meyer and Lofgreen reported a method for determining crude fiber that was more highly correlated with animal digestibility than previous methods. Changes in the initial extraction procedure and elimination of the final ashing process reduced analysis time to 4 hours and resulted in a crude fiber plus ash (primarily silica) fraction which was highly correlated with *in vivo* digestibility ($r = -0.89$). A high correlation was also found between MCF and digestible protein ($r = 0.86$), but the chemical analysis most highly related to digestible protein was crude protein ($r = 0.99$).

DIVISION BY DETERGENTS

Plant material also can be divided into cell contents and cell walls (Van Soest and Moore, 1965; Van Soest, 1967). Cell contents consist of sugars, starch, soluble carbohydrates, pectin, non-protein nitrogen, protein, lipids, minerals, and vitamins. Because these cell contents are 98 percent digestible, they can be considered a nutritional unit. Cell contents are dissolved in a boiling, buffered neutral detergent reagent (sodium lauryl sulfate).

The remaining fibrous fraction, or neutral detergent fiber (NDF), is not a nutritionally uniform unit. It contains cellulose, hemicellulose, silica, lignin, cutin, insoluble minerals, and lignocellulose. Hemicellulose and cellulose are partially digestible by ruminant animals. Lignin and silica are nondigestible and may affect the digestibility of the digestible cell wall materials. The partially digestible cell wall fraction can be separated from the indigestible fraction with an acid detergent (cetyltrimethyl ammonium bromide in H_2SO_4). This treatment dissolves the partially digestible hemicellulose complex but leaves lignocellulose. The cellulose is dissolved by 72 percent H_2SO_4, which leaves the lignin fraction. An alternate procedure involves removing the lignin with saturated $KMnO_4$. This leaves the cellulose fraction. Ashing removes the cellulose and leaves the minerals. True feed digestibility is thus the sum of the digestibility of the cell contents and the cell walls.

High correlations have been found between the *in vivo* digestibility of the cell contents, cell wall, and lignin fraction with *in vitro* data (Van Soest and Moore, 1965, 1967). *In vitro* rumen procedures (Tilley and Terry, 1963) yield even more accurate estimates of digestibilities than chemical methods. This is because of the sensitivity of rumen-digesting bacteria to factors not considered in chemical methods.

In vitro procedures should be considered if facilities are available for rumen fluid and laboratory ventilation to remove objectionable odors, as IVDMD (*in vitro* dry matter digestibility) analyses can be performed in approximately half the time of the combination of neutral detergent fiber (NDF) and acid detergent fiber (ADF) analyses. The simplicity of chemical analysis methods (CP, NDF, and ADF) and their relatively high correlation with animal performance have led to their general usage in routine analysis of hay.

AFGC TASK FORCE

In 1972, the American Forage and Grassland Council (AFGC) formed a hay marketing task force to:

1. Identify hay marketing problems,
2. Determine problem priorities and possible practical solutions, and
3. Develop specific recommendations for action.

A hay marketing subcommittee of the AFGC, which included Extension specialists, researchers, and industry representatives, recommended that neutral detergent fiber and acid detergent fiber analyses be used as the chemical assays to estimate actual animal dry matter intake and dry matter digestibility, respectively. In 1975, the subcommittee recommended the establishment of new standards for hay based upon chemical composition as related to animal performance data. The standard grades previously used for hay (revised in 1949) were based upon organoleptic properties (color, smell, and presence or absence of foreign material).

NEW HAY STANDARDS

New hay standards proposed by the Forage Analysis Subcommittee were modified by the Federal Grain Inspection Service in June 1978. Based upon further research data, the calculation of relative feeding value (RFV) was refined in September 1979. In the proposed standards, legumes, grasses, and legume-grass mixtures are evaluated on a common continuum that allows a calculation of the relative feeding value for plants. Both chemical analyses (CP, NDF, and ADF) and organoleptic characteristics (sight, smell, and touch) would be used to establish the five hay grades, with only descriptive material used to establish a sample grade.

RESEARCH REPORTS

I. Alfalfa Hay Quality Characteristics as Affected by Geographical Location and Cutting

INTRODUCTION

In response to the development of new hay standards based upon chemical analyses, an alfalfa hay quality experiment was initiated by the Klamath Agricultural Experiment Station of Oregon State University. This research project was designed to examine various quality characteristics of alfalfa hay from five regions of Oregon. These regions correspond to the Oregon Hay Growers Association (OHGA) districts (Fig. 1).

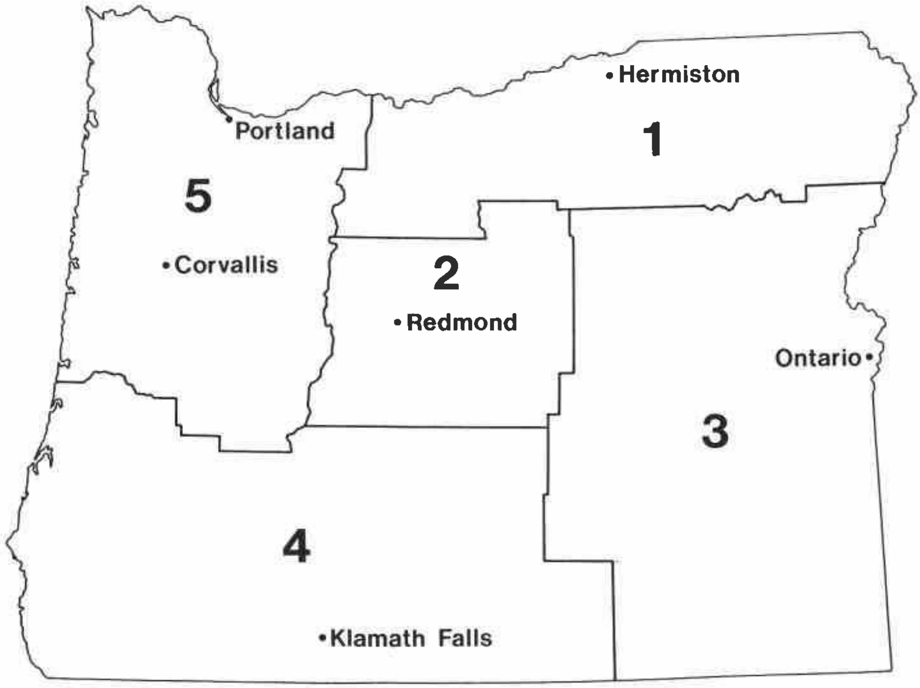

Figure 1. Oregon Hay Growers Association districts. Districts 1 to 5 are characterized by elevations of <1,500 feet, 3,000 to 3,700 feet, 2,000 to 2,500 feet, >4,000 feet, and <1,500 feet, respectively.

MATERIALS AND METHODS

In 1977 and 1978, 433 samples of alfalfa hay were taken, encompassing all five OHGA districts, with three or four cuttings obtained for each year. Sampling was done on a grower-request basis. The number of samples obtained from each district was 101, 23, 13, 250, and 46. Samples for the four cuttings numbered 235, 116, 28, and 54. In 1977, 143 samples were collected and in 1978, 290 were collected. Samples were taken from hay bales with a "Penn State" forage sampler attached to a power drill (Barnes, 1973). Twenty cores were taken from each lot of hay, one each from bales selected at random. Cores for each lot were then pooled for analyses to determine hay quality characteristics with respect to year, location, and cutting. Analyses for crude protein (CP), NDF, ADF, calcium (Ca), and phosphorus (P) were performed at the OSU Forage Testing Laboratory. *In vitro* dry matter digestibility (IVDMD) was determined at the Klamath Agricultural Experiment Station laboratory. A modified Kjeldahl procedure (AOAC, 1970) was used to determine CP; NDF and ADF were determined by the method of Goering and Van Soest (1970) as described by Barnes (1973). Relative feed value calculations were made as described in Table 1. Values for IVDMD

Table 1. Proposed market hay grades for alfalfa based upon chemical composition†

Grade	CP	NDF	DMI	ADF	*In vivo* DDM	DDMI	RFV‡
	%	%	g/kg $W^{0.75}$	%	%	g/kg $W^{0.75}$	
1	>19	<40	>140	<31	>69	>96	>140
2	17-19	40-45	129-139	31-35	66-68	85-95	124-140
3	13-16	46-51	120-138	36-41	59-65	71-84	101-123
4	<13	>51	<120	>41	<58	<70	<100

Compiled from D. A. Rohweder and J. E. Baylor, 1980, Forage and Grassland Progress, Vol. 20.

†CP = crude protein, NDF = neutral detergent fiber, DMI = dry matter intake (expressed as g/kg body weight$^{0.75}$), ADF = acid detergent fiber, DDM = digestible dry matter, DDMI = digestible dry matter intake, RFV = relative feed value.

‡Formulas used to calculate RFV for alfalfa:

$DDM = 34.12 + 2.64(\%ADF) - 0.05(\%ADF^2)$;

$DMI = 146.96 + 1.01(\%NDF) - 0.03(\%NDF^2)$;

$DDMI = DDM(DMI/100)$;

$RFV = DDMI(1.43)$.

were determined by the method of Tilley and Terry (1963), using rumen fluid from a fistulated steer fed an alfalfa diet. Calcium determination was by atomic absorption spectroscopy. Phosphorus was colorimetrically determined by the phosphomolybdate method of Fiske and Subbarow (1925). Analyses of variance were calculated for each laboratory analysis to determine differences from geographical location, cutting, and year.

RESULTS

No significant differences due to year were noted for CP, NDF, ADF, or RFV. *In vitro* dry matter digestibility (IVDMD), Ca, and P were significantly increased in 1978 (Table 2). Mean values for CP ranged

Table 2. Analysis of 433 alfalfa hay samples (1977-1978)†

Year	CP	NDF	ADF	RFV	IVDMD	Ca	P
	%	%	%		%	%	%
1977	17.7	42.2	32.6	130.5	64.7	0.91	0.30
1978	17.7	41.7	32.5	131.4	66.4**	1.23**	0.32**

† CP = crude protein, NDF = neutral detergent fiber, ADF = acid detergent fiber, RFV = relative feed value, IVDMD = *in vitro* dry matter digestibility, Ca = calcium, P = phosphorus.

** Indicates significant difference (probability less than 0.01) within columns.

from 16.9 to 17.9 percent (dry weight basis) for all districts (Fig. 2). No significant differences were noted due to location, but less variability from the mean value for District 4 may indicate a more uniform level of CP in hay from the Klamath Falls area in addition to the greater number of samples from that district. Greater differences in CP values were related to stage of maturity or cutting. Cuttings 2 and 3 averaged slightly more than 18.5 percent CP, while Cuttings 1 and 4 were less than 17.2 percent and 17.6 percent respectively (Fig. 3). Cutting 1 was significantly

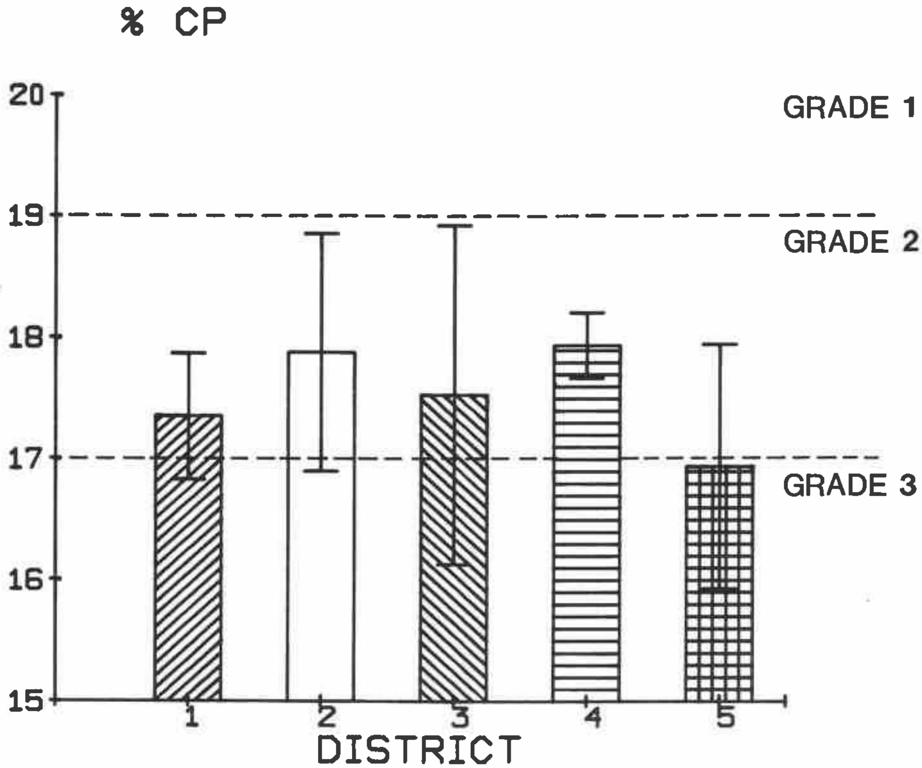

Figure 2. Crude protein (CP) concentration of 433 alfalfa hay samples as a function of district (95% confidence intervals are provided for each mean value).

lower than Cutting 2. Cuttings 3 and 4 were not significantly different from Cutting 1 as indicated by overlapping confidence interval limits.

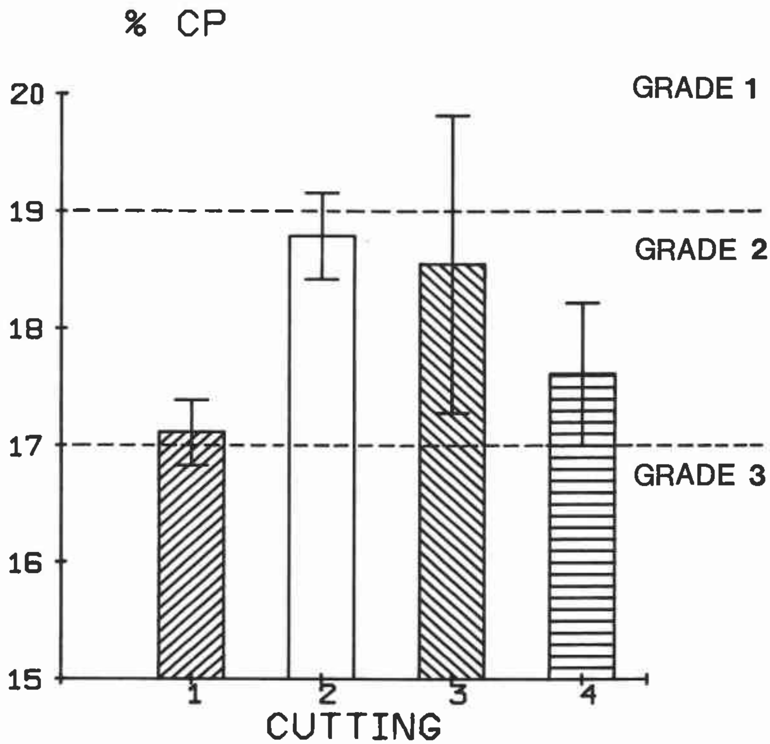

Figure 3. Crude protein (CP) concentration of 433 alfalfa hay samples as a function of cutting (95% confidence intervals are provided for each mean value).

Neutral detergent fiber mean values ranged from 41.3 to 43.3 percent, with no significant differences observed among districts (Fig. 4). Cutting 1 (42.9%) was significantly higher in NDF than Cutting 2 (40.1%) but was not significantly different from Cuttings 3 and 4 (Fig. 5). Mean ADF values ranged from 31.8 to 34.2 percent as a function of geographical location (Fig. 6). Mean values from Districts 1 and 5 were significantly higher than those from District 4. No significant differences were observed due to cutting, though Cutting 3 confidence intervals ranged from 29.8 to 35.5 percent ADF (Fig. 7).

Districts 1 through 4 and all cutting mean values for RFV were in the Grade 2 category (124 to 140 RFV) as shown in Figures 8 and 9. The mean value for District 5 was only 0.2 RFV units below the value for Grade 2. District 4 approached a significantly higher average value than District 1, though mean values for all locations, ranging from 124 to 131,

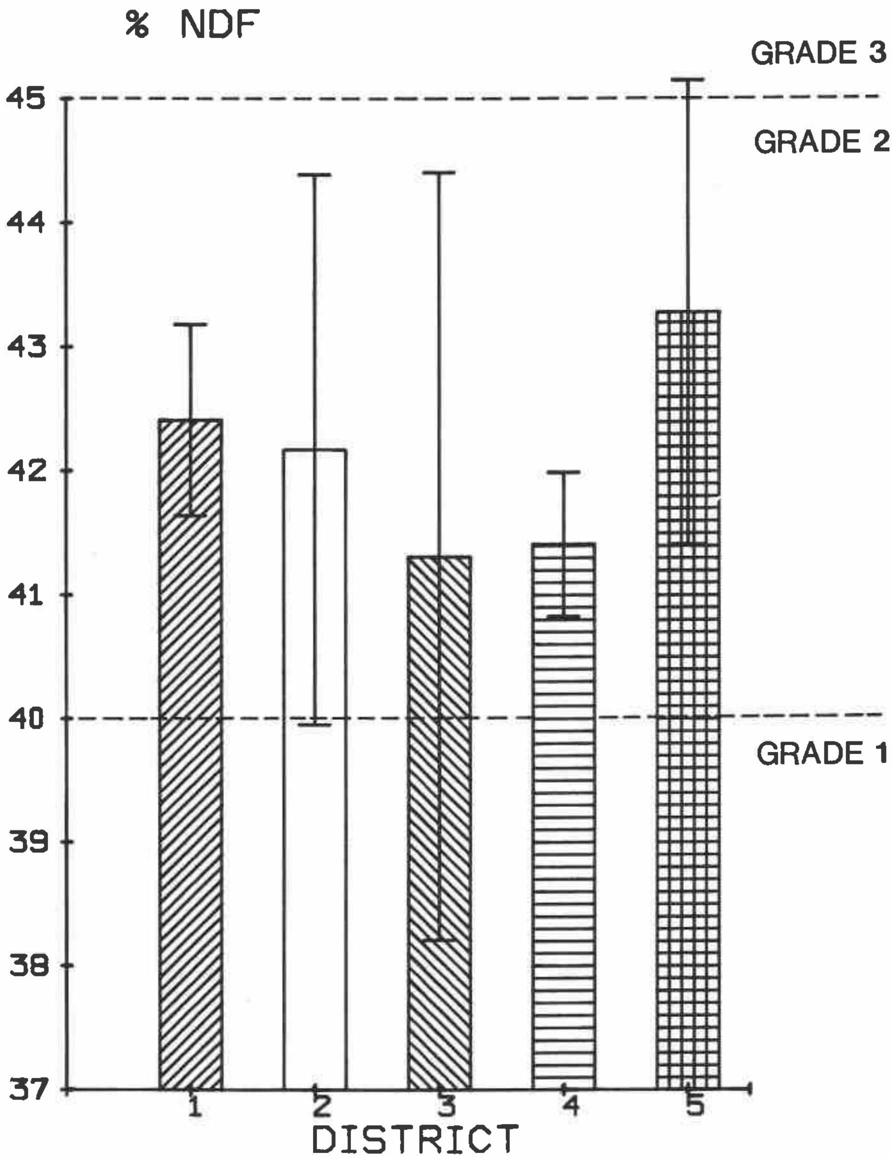

Figure 4. Neutral detergent fiber (NDF) concentration of 433 alfalfa hay samples as a function of district (95% confidence intervals are provided for each mean value).

represented only seven RFV units, a very small difference. Cutting 2 was significantly higher in RFV than Cutting 1 (133, 128) but was not significantly higher than Cuttings 3 and 4 (126, 129).

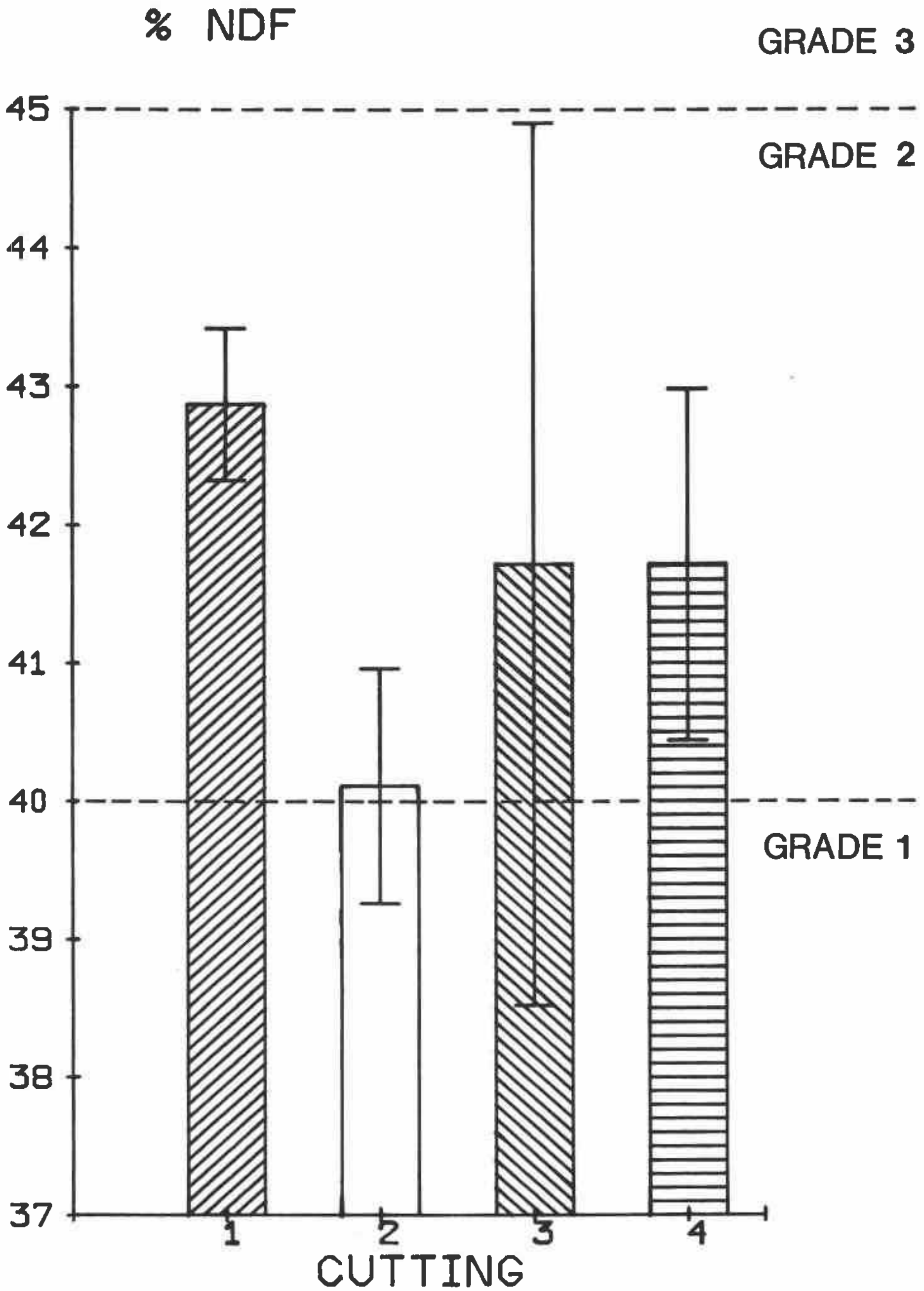

Figure 5. Neutral detergent fiber (NDF) concentration of 433 alfalfa hay samples as a function of cutting (95% confidence intervals are provided for each mean value).

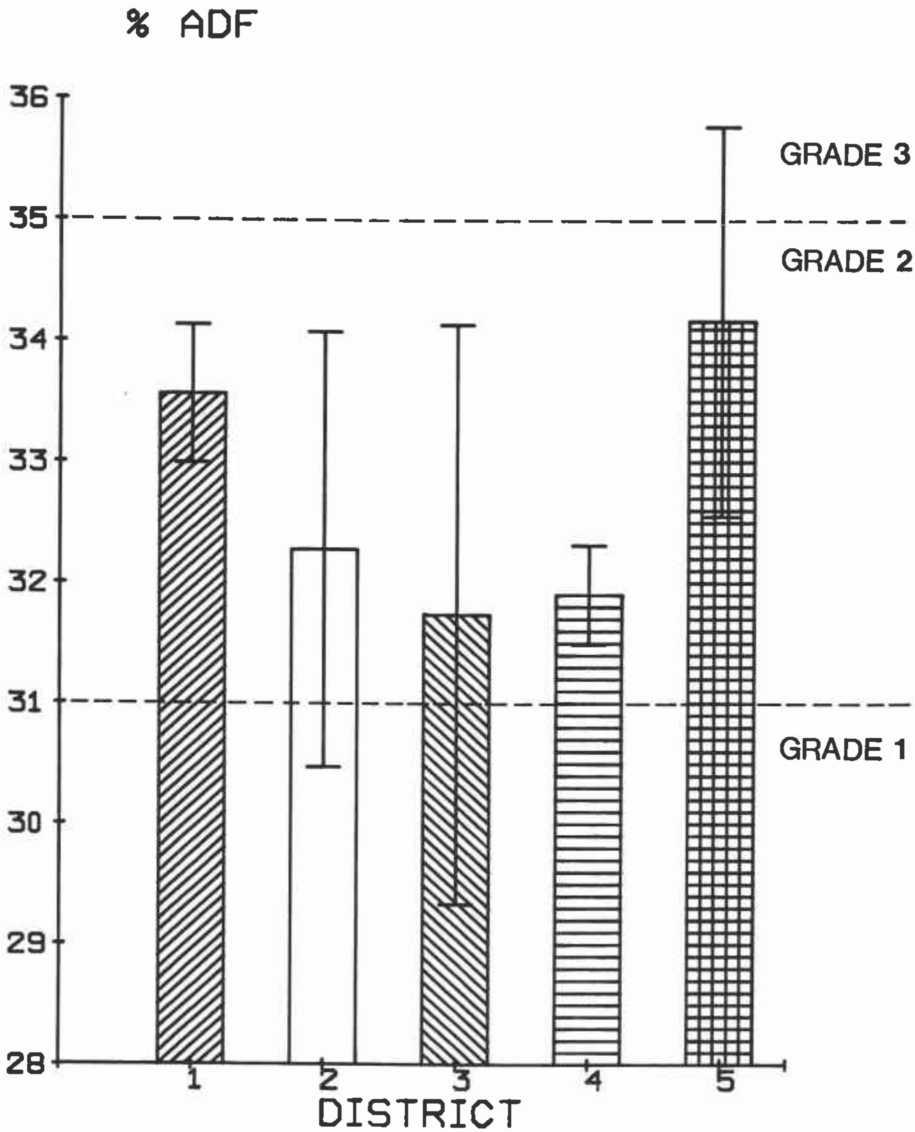

Figure 6. Acid detergent fiber (ADF) concentration of 433 alfalfa hay samples as a function of district (95% confidence intervals are provided for each mean value).

Mean values for IVDMD for districts ranged from 65.3 to 66.1 percent with no significant differences noted (Fig. 10). Cutting differences were also insignificant, with a range of values from 64.8 to 66.2 percent IVDMD (Fig. 11). Mean Ca concentrations for districts ranged from 1.04 to 1.26 percent, with significant differences only between Districts 1 and

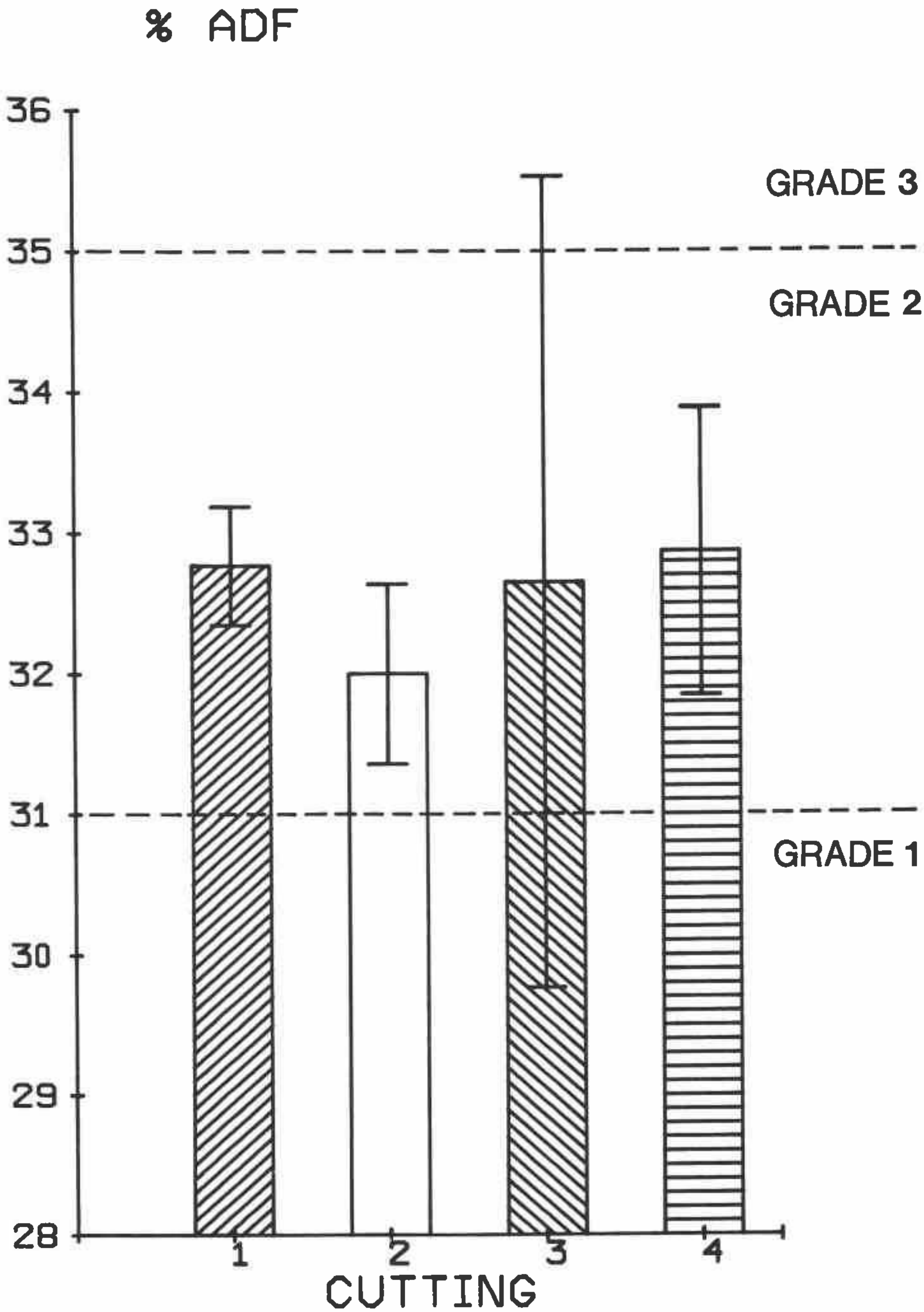

Figure 7. Acid detergent fiber (ADF) concentration of 433 alfalfa hay samples as a function of cutting (95% confidence intervals are provided for each mean value).

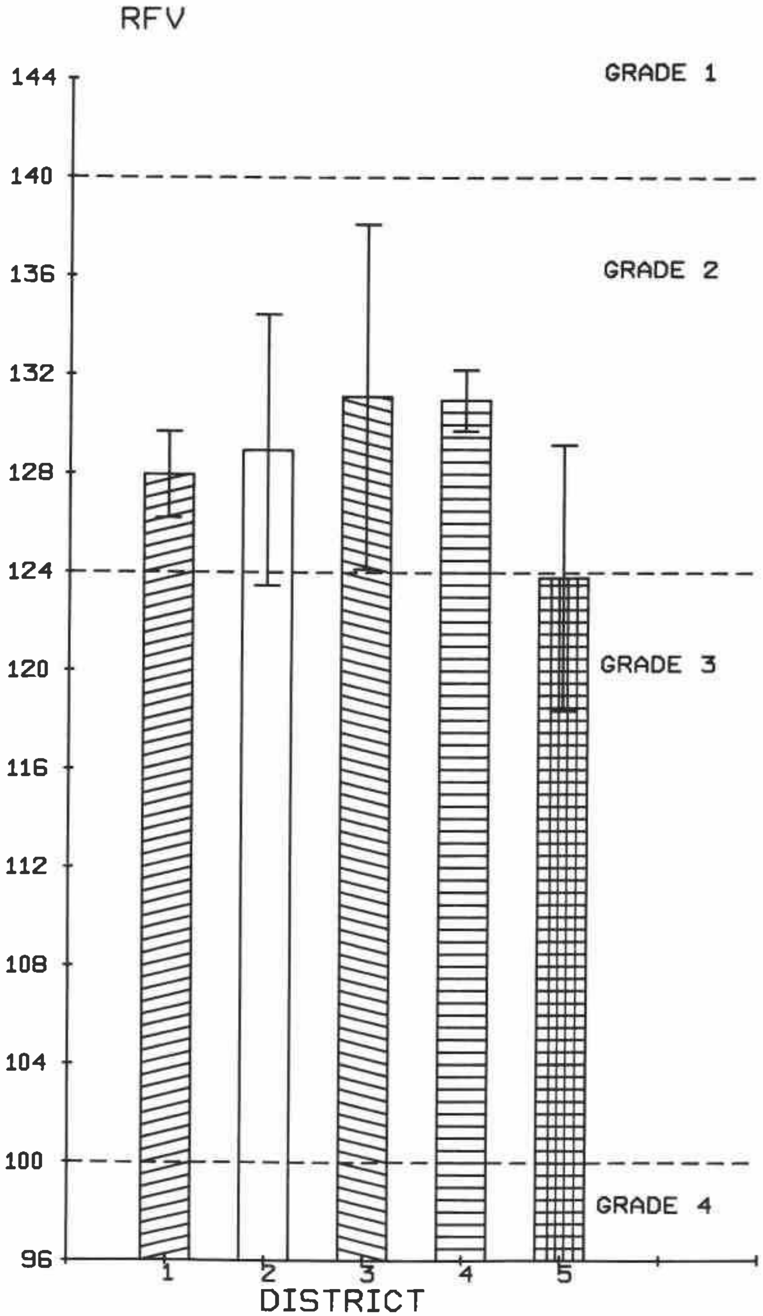

Figure 8. Relative feed value (RFV) for 433 alfalfa hay samples as a function of district (95% confidence intervals are provided for each mean value).

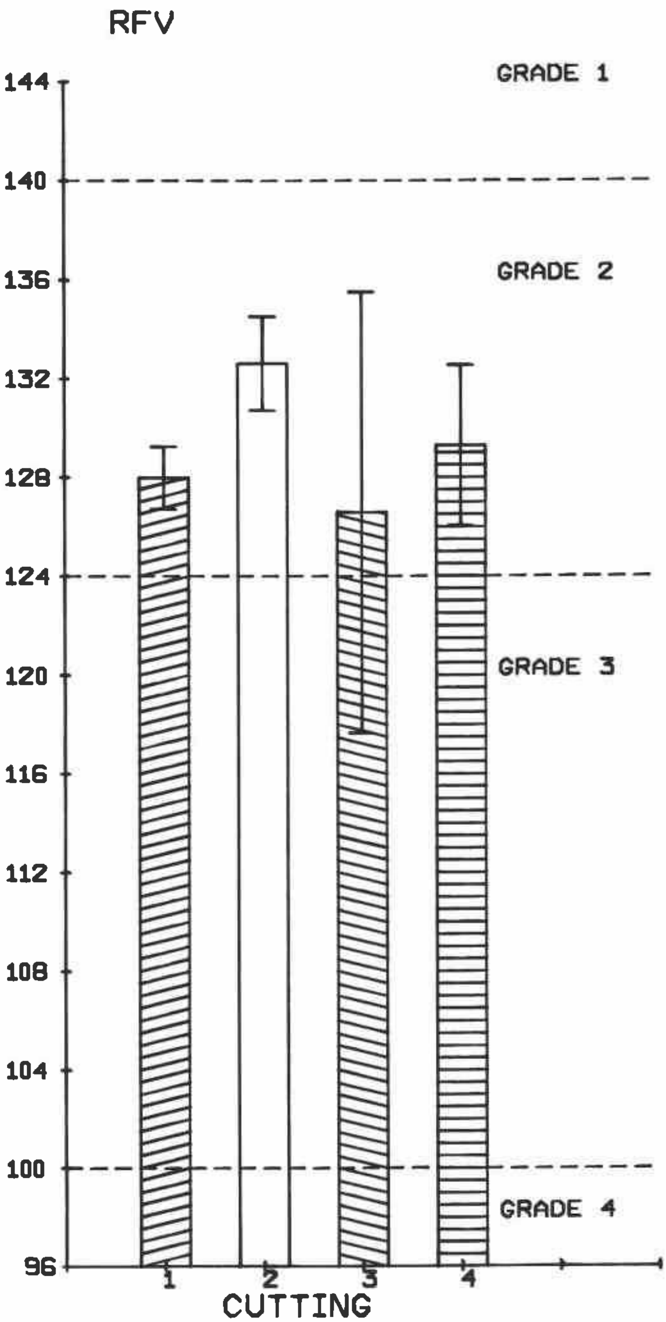

Figure 9. Relative feed value (RFV) of 433 alfalfa hay samples as a function of cutting (95% confidence intervals are provided for each mean value).

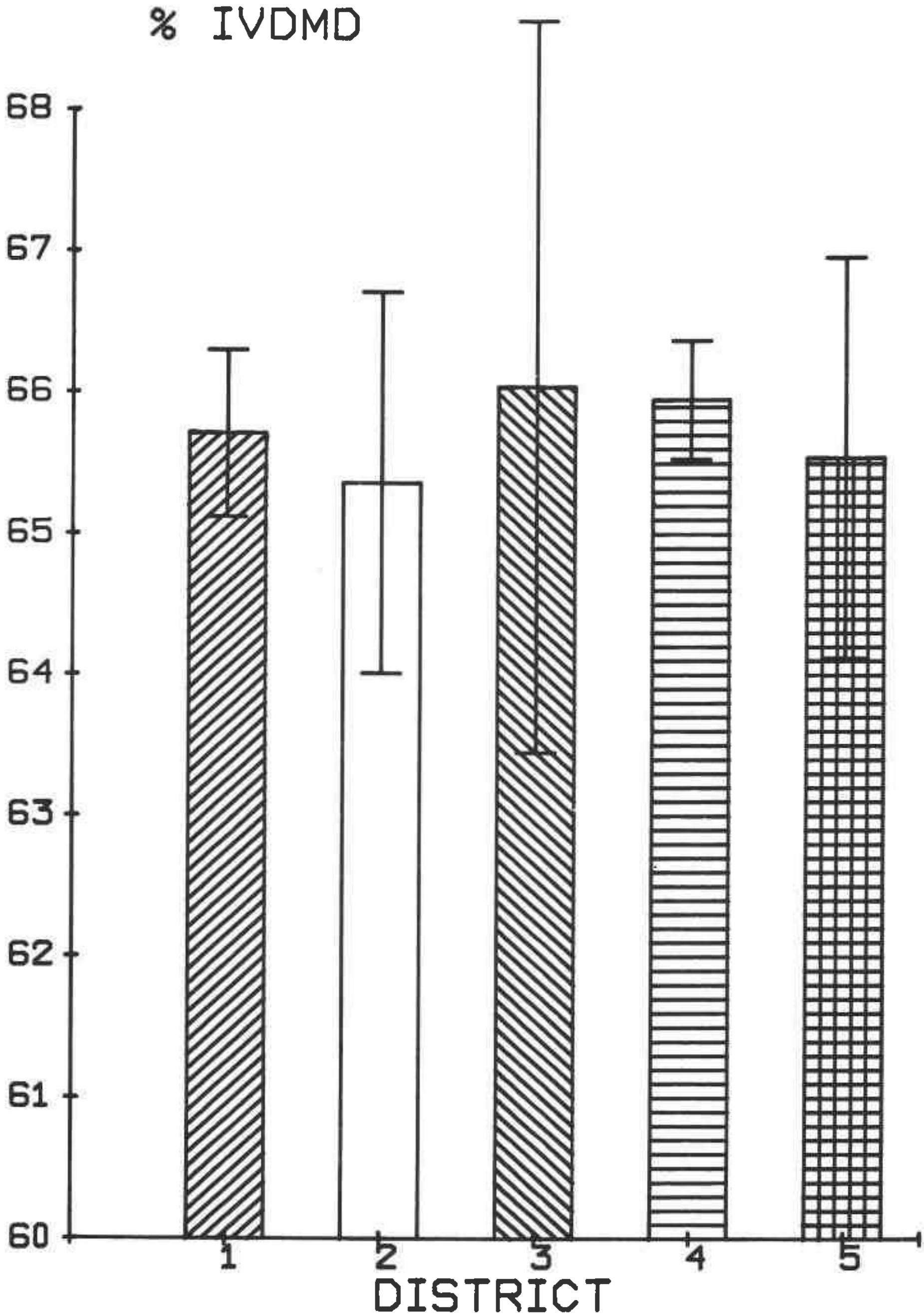

Figure 10. ***In vitro*** **dry matter digestibility (IVDMD) of 433 alfalfa hay samples as a function of district (95% confidence intervals are provided for each mean value).**

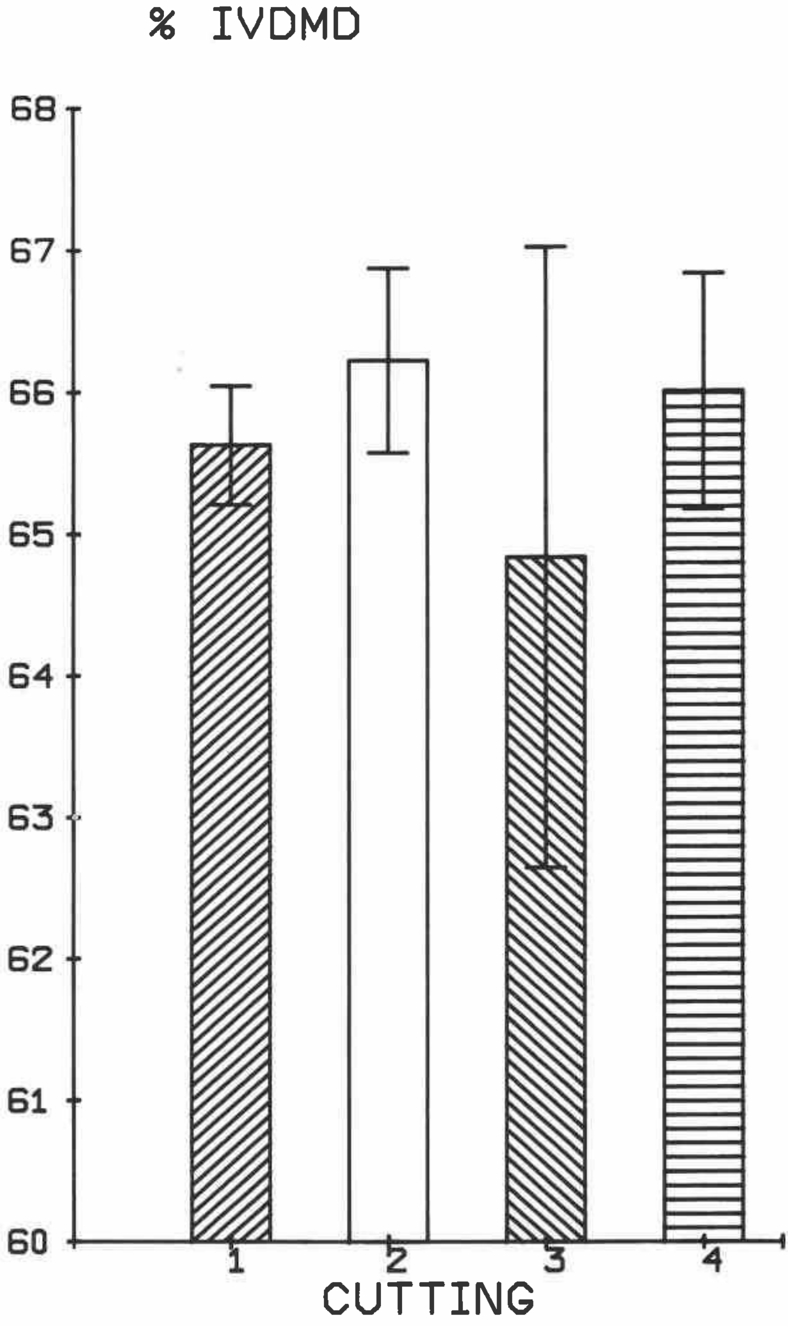

Figure 11. *In vitro* dry matter digestibility (IVDMD) of 433 alfalfa hay samples as a function of cutting (95% confidence intervals are provided for each mean value).

4 (Fig. 12). Mean Ca values (Fig. 13) were lowest in Cutting 1 (1.04%) and significantly lower than those in Cutting 3 (1.24%).

Phosphorus concentrations were not significantly influenced by location or cutting. The lowest mean P value (0.29%) was found in District 3

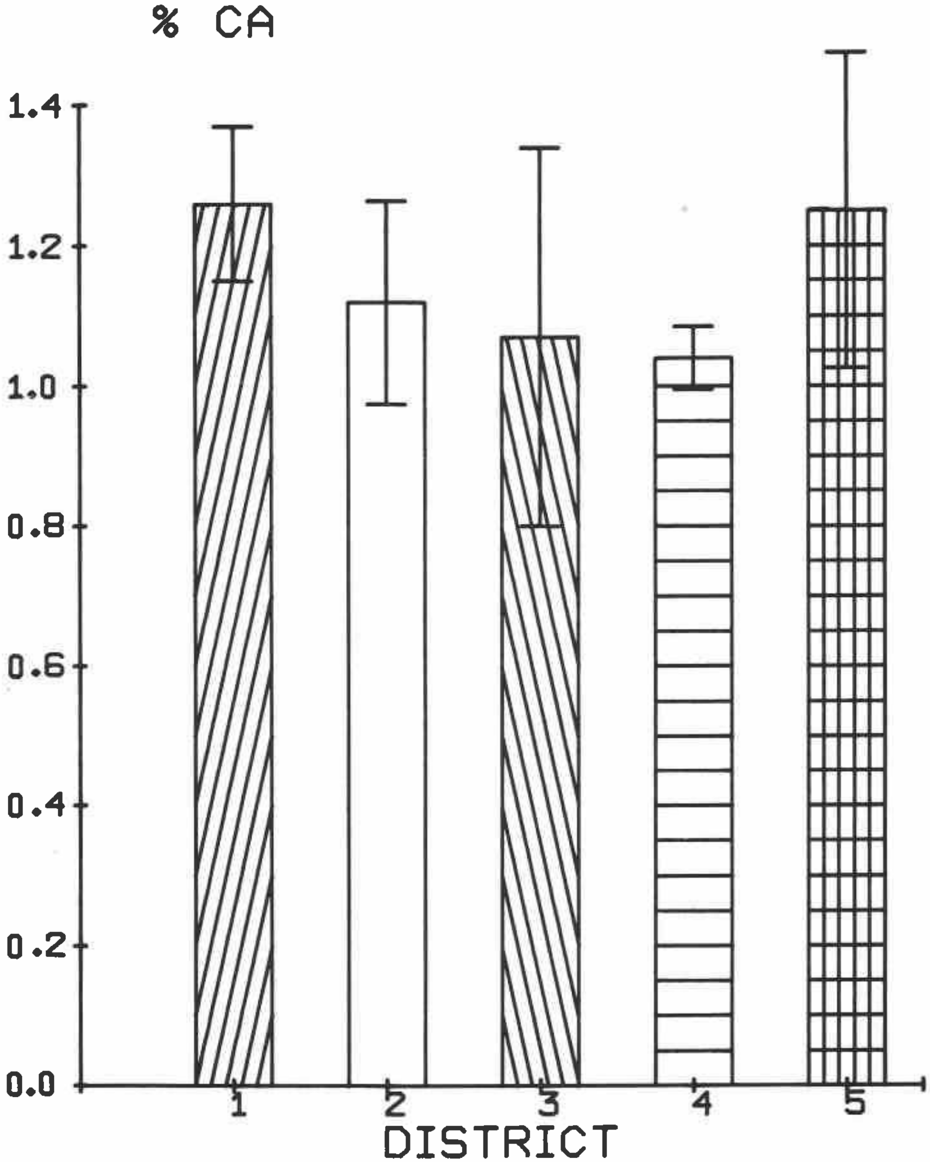

Figure 12. Calcium (Ca) concentration of 433 alfalfa hay samples as a function of district (95% confidence intervals are provided for each mean value).

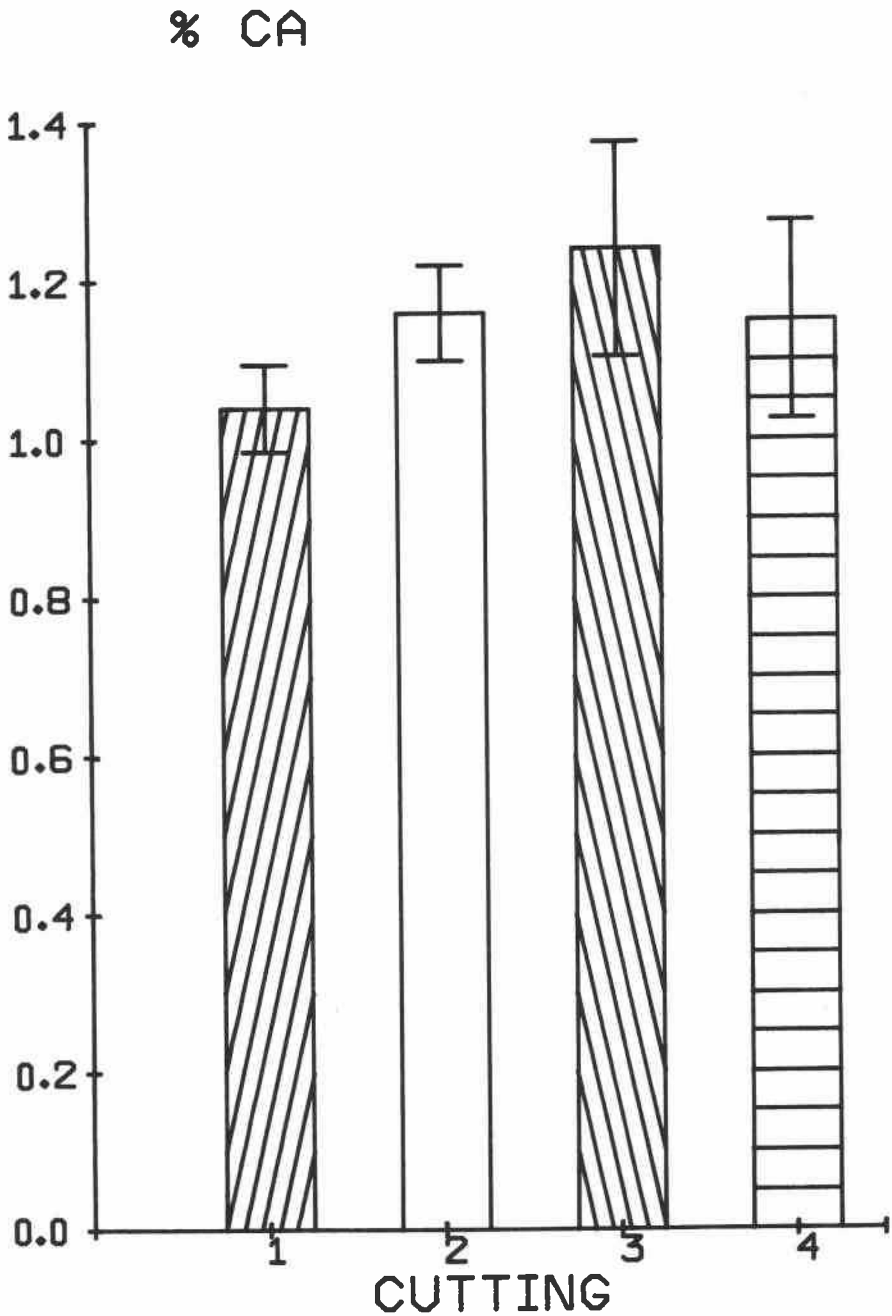

Figure 13. Calcium (Ca) concentration of 433 alfalfa hay samples as a function of cutting (95% confidence intervals are provided for each mean value).

and the highest (0.34%) in District 2 (Fig. 14). Mean cutting P values ranged between 0.31 and 0.32 percent P (Fig. 15).

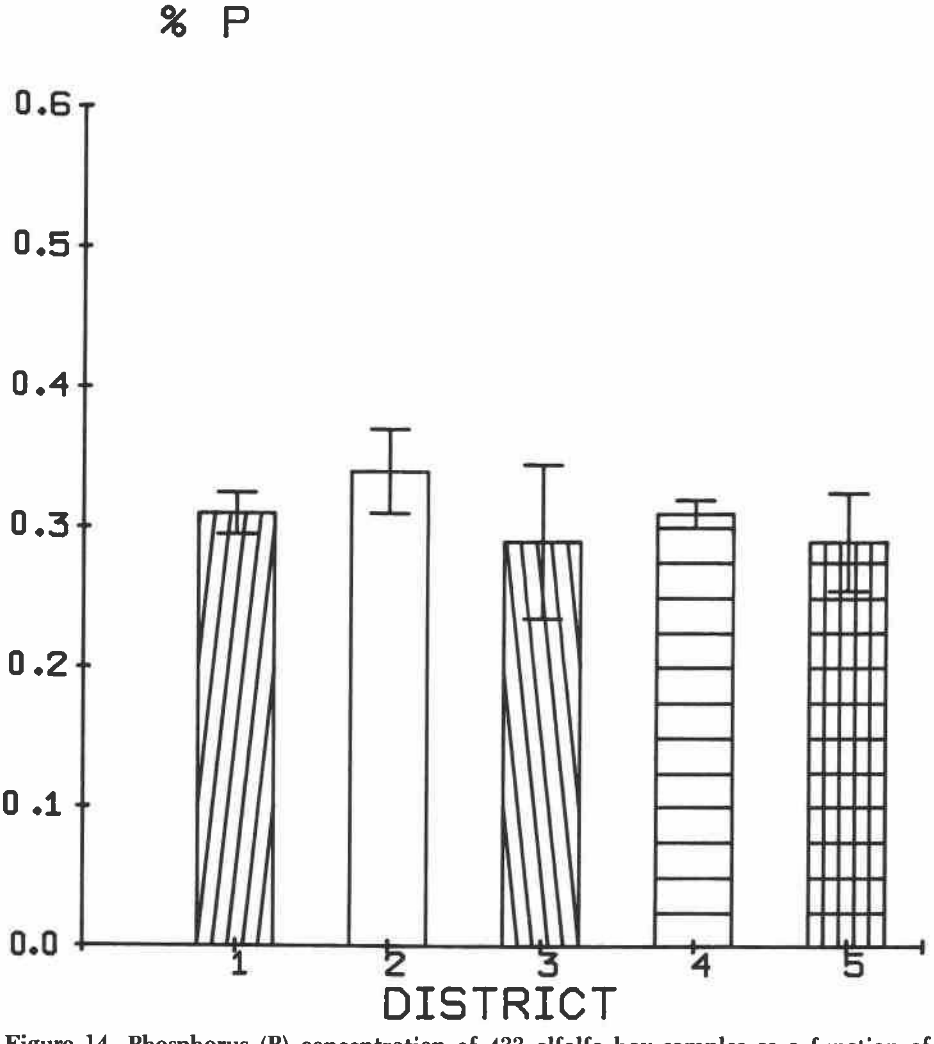

Figure 14. Phosphorus (P) concentration of 433 alfalfa hay samples as a function of district (95% confidence intervals are provided for each mean value).

The correlation between NDF and ADF was the highest (0.83) obtained among analyses. This positive correlation was reflected in the correlation of NDF and ADF with IVDMD and CP. The direction and strength of relationships were similar for both of the fiber analyses (Table 3). Both fiber analyses were negatively correlated with CP and IVDMD, with the correlation in IVDMD slightly stronger than that of CP.

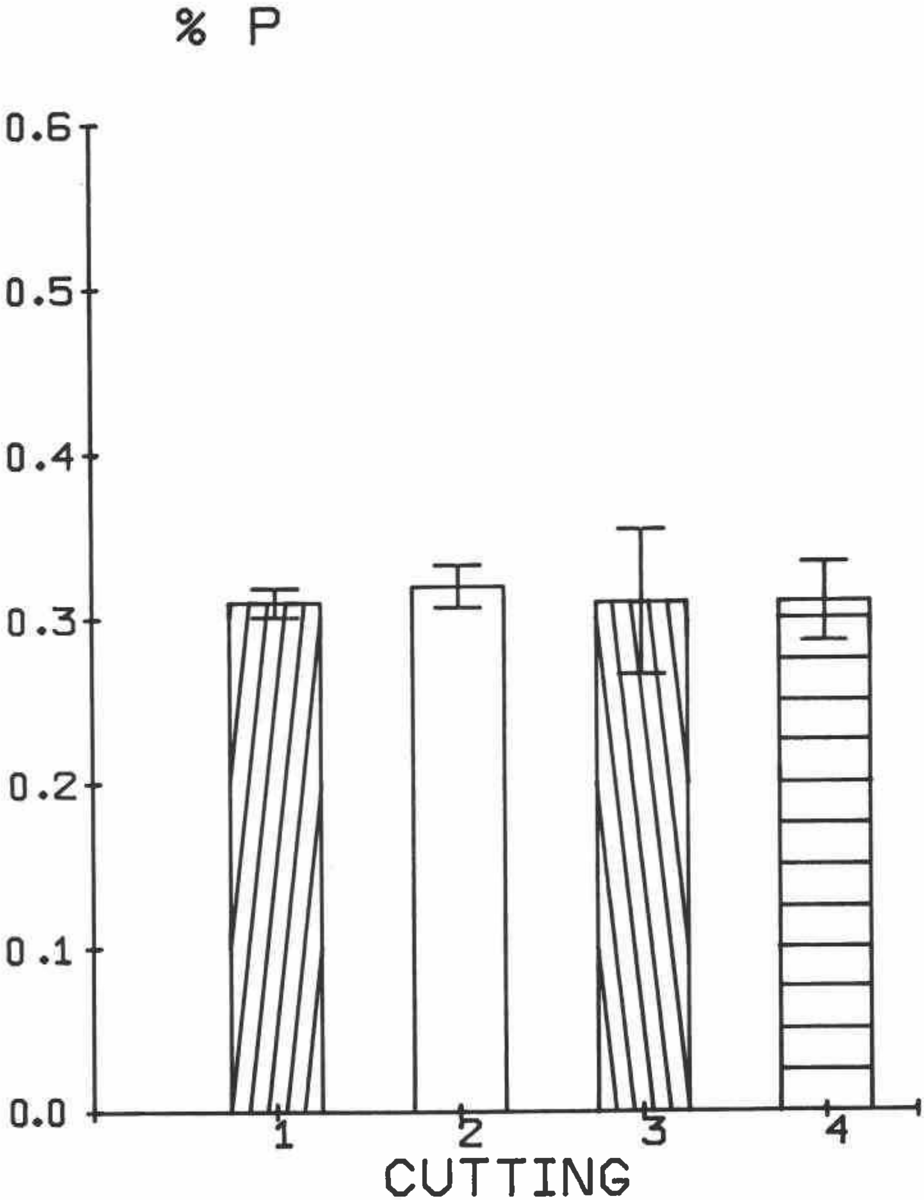

Figure 15. Phosphorus (P) concentration of 433 alfalfa hay samples as a function of cutting (95% confidence intervals are provided for each mean value).

Table 3. Correlation coefficients among protein, fiber, and dry matter digestibility of 433 samples of alfalfa hay (1977-1978)

	r
Neutral detergent fiber: acid detergent fiber	0.83***
Crude protein: acid detergent fiber	–0.56***
Crude protein: neutral detergent fiber	–0.62***
Neutral detergent fiber: *in vitro* dry matter digestibility	–0.64***
Acid detergent fiber: *in vitro* dry matter digestibility	–0.66***
Crude protein: *in vitro* dry matter digestibility	0.49***

*** Significant at the 0.1% level of probability.

DISCUSSION

Although significant differences among districts and cuttings were observed for some of the analyses, the more important aspect of this evaluation of hay quality was the lack of differences from geographical regions and cuttings. This may be caused in part by a skewed sample base because samples were taken at grower request and probably represent some of the better hay in the state.

The consensus in Oregon has been that certain higher elevation alfalfa-producing regions were able to produce significantly higher quality hay. However, these data suggest that factors other than geographical region or time of cutting are more important in determining hay quality.

The consensus that hays produced in high altitudes are of higher quality, on the average, cannot be wholly discounted by the data in this study because Districts 2, 3, and 4 were higher in CP and RFV and lower in NDF and ADF. However, the narrow range of values for all analyses indicates a greater possibility for growing high-quality alfalfa in diverse climatic regions and management systems than previously thought.

The most important management decision for producing high-quality alfalfa hay is cutting at the proper stage of growth. Cutting in the late bud stage, when plants have a high proportion of leaves and low proportion of indigestible fiber, will result in the highest quality hay. Relative feed values of hay cut at this stage of maturity will be 140 and above (Table 1).

These data indicate the need for examining and testing the quality of hay before purchase. In this way high-quality hay can be obtained from areas not previously identified with high-quality hay.

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II. The Relationship of Neutral Detergent Fiber and Acid Detergent Fiber of Alfalfa Hay to Nutritive Value for Steers

INTRODUCTION

In the proposed hay grading system, neutral detergent fiber (NDF) and acid detergent fiber (ADF) components of forage are used to predict voluntary dry matter intake (VDMI) and digestible dry matter (DDM) respectively. As previously described, NDF and ADF are fractions of plant cell walls that are determined by an analytical procedure (Goering and Van Soest, 1970) that has widely replaced the crude fiber procedure of the Weende proximate analysis system (Cappock and Woelfel, 1980).

To determine how well the new hay grading standards reflected digestibility of Oregon-grown hays, hay that was obtained and tested in Oregon was used in three steer digestion trials. Results of these digestion trials were then used to determine the relationship between the chemical components (CP, NDF, ADF) of alfalfa hays grown in central Oregon and performance of steers as measured by VDMI and DDM.

MATERIALS AND METHODS

Three digestibility trials were conducted. Each trial involved four lots of alfalfa hay and four Holstein steers in a 4 x 4 Latin square experimental design. The composition of the hays ranged from 14 to 22 percent CP, from 34 to 56 percent NDF, and from 26 to 44 percent ADF (Table 1 of Research Report II). For each trial, two low-protein and two

Table 1. Composition of alfalfa hays

Trial Number	Lot Number	Crude protein	Neutral detergent fiber	Acid detergent fiber	Cutting No.
		...................% dry matter	....		
1 (1977)	1	15.7	55.8	43.9	2
	2	15.4	45.9	39.9	1
	3	19.1	40.2	32.6	2
	4	17.2	42.2	35.2	2
2 (1978)	1	15.4	48.0	40.3	1
	2	14.1	47.1	35.7	1
	3	19.0	42.2	36.4	1
	4	18.0	39.8	35.6	1
3 (1979)	1	15.9	48.5	38.4	1
	2	16.1	46.5	37.8	1
	3	21.9	33.9	25.7	3
	4	19.4	38.8	29.4	1

high-protein hays were selected. All hays were from the Klamath Basin, with the exception of Lots 1 and 2 in Trial 3, which were from the Columbia River Plateau. The Klamath Basin is a major hay-producing area between 42 and 43°N latitude at an altitude of approximately 1,800 meters. Mean temperatures range from 7.7° to 15.3°C during May and June and from 15.6° to 20.0°C in August through September. All hays were harvested into and stored as bales, but they were chopped with a bale shredder at the beginning of each digestion trial.

The steers were fed approximately equal portions of hay three times daily. Immediately before the morning feeding, all uneaten hay was weighed to determine daily consumption. Only mineralized salt blocks and water were available to the steers in addition to hay.

Each experiment lasted four weeks. Daily intake during the second week was averaged to estimate VDMI. The quantity of hay fed during the remaining two weeks was reduced to 85 percent of the estimated VDMI to ensure a constant daily intake. On the second day of the fourth week, the steers were fitted with fecal collection bags for the last five days of the experiments. Total daily excrements were weighed and 100-gram aliquots from each steer were combined and stored in sealed jars containing 100 grams of 2 percent HCl.

Dry matter of composite samples of hay and feces was determined by air drying at 55°C for 72 hours, grinding, and oven drying at 80°C for 24 hours. Macro-Kjeldahl procedures (AOAC, 1970) were used to determine CP, and the method of Goering and Van Soest (1970) as described by Barnes (1973) was used to determine NDF and ADF.

RESULTS

The correlation coefficients obtained between the chemical components (CP, NDF, ADF) of the alfalfa hays and the performance of the steers (VDMI, DDM) show that DDM was as closely associated with NDF as with ADF (Table 2 of Research Report II). Other studies have shown ADF to be more highly correlated than NDF with DDM (Van Soest and Mertens, 1977; Rohweder et al., 1978), and, therefore, the measurement chosen for predicting DDM. Correlation coefficients reported range between −0.75 and −0.91, depending upon growing area, with a composite correlation of −0.82 for alfalfa hays from all areas (Rohweder, 1978). The composite correlation is similar to that obtained in this study (r = — 0.77). However, in contrast to other studies, VDMI was found to be more closely related to ADF than to NDF (Table 2 of Report II). The correlation coefficient between VDMI and ADF (r = — 0.62) is of the same magnitude as that reported by Rohweder and others (1978) between VDMI and NDF.

Table 2. Correlation coefficients between chemical components of alfalfa hays and performance of steers

	r	
Chemical components†	Individual steers (n = 48)	Treatment group means (n = 12)
CP:NDF	----	–0.83
CP:ADF	----	–0.81
NDF:ADF	----	0.92
CP:VDMI	0.33	0.37
NDF:VDMI	–0.54	–0.51
ADF:VDMI	–0.52	–0.63
CP:DDM	0.37	0.54
NDF:DDM	–0.55	–0.79
ADF:DDM	–0.52	–0.77
DDM:IVDDM	0.59	0.89

† CP = crude protein, NDF = neutral detergent fiber, ADF = acid detergent fiber, VDMI = voluntary dry matter intake, DDM = digestible dry matter, IVDDM = *in vitro* digestible dry matter.

The correlation coefficients between chemical components and performance for the average of the four steers are substantially larger than those for individual animals, with the exception of that between NDF and VDMI (Table 2 of Report II). These differences reflect the effect of individual animal variation and emphasize the need for using group averages rather than individual values.

Regression equations were developed to predict DDM from NDF and ADF and to predict VDMI from ADF (Table 3 of Report II). The

Table 3. Regression equations for predicting voluntary dry matter intake and digestible dry matter from neutral detergent fiber or acid detergent fiber

Description	r	R^2
1. *In vivo* % digestible dry matter (DDM)		
Neutral detergent fiber:		
DDM = 88.587 – .538 (NDF)	–0.79	0.63
DDM = 38.711 + 1.657 (NDF) – .0238 (NDF^2)	–0.82	0.67
Acid detergent fiber:		
DDM = 87.092 – .623 (ADF)	–0.77	0.59
DDM = 38.848 + 2.100 (ADF) – .0378 (ADF^2)	–0.81	0.66
2. Voluntary dry matter intake (VDMI)		
Acid detergent fiber:		
VDMI = 103.933 – 1.176 (ADF)	–0.63	0.40
VDMI = 151.152 – 3.84 (ADF) + .037 (ADF^2)	–0.64	0.41

quadratic equations appear to substantially improve the coefficient of determination (R^2) between DDM and both NDF and ADF over that of the linear equations. This is particularly true for the equation predicting DDM from ADF, which estimates DDM as precisely as the equation for NDF or the equation reported by Rohweder and others (1978). In contrast, the quadratic equation for predicting VDMI from ADF (Table 3 of Report II) does not improve the prediction over that of the linear equation.

These regression equations suggest that only ADF is needed to predict both DDM and VDMI of the alfalfas grown in the high elevation area of the Klamath Basin. By applying ADF percentage of a given alfalfa to the linear equation and to the quadratic equation, VDMI and DDM can be predicted. The mean values and confidence intervals (probability = 0.05) for percent VDMI and DDM, (g/kg $W^{0.75}$) predicted from ADF percentages between 25 and 45 are shown in Figures 1 and 2 of Report II. By using DDM and VDMI from these figures, daily DDM intake can be estimated for any mature bovine of known body weight that is fed alfalfa hay.

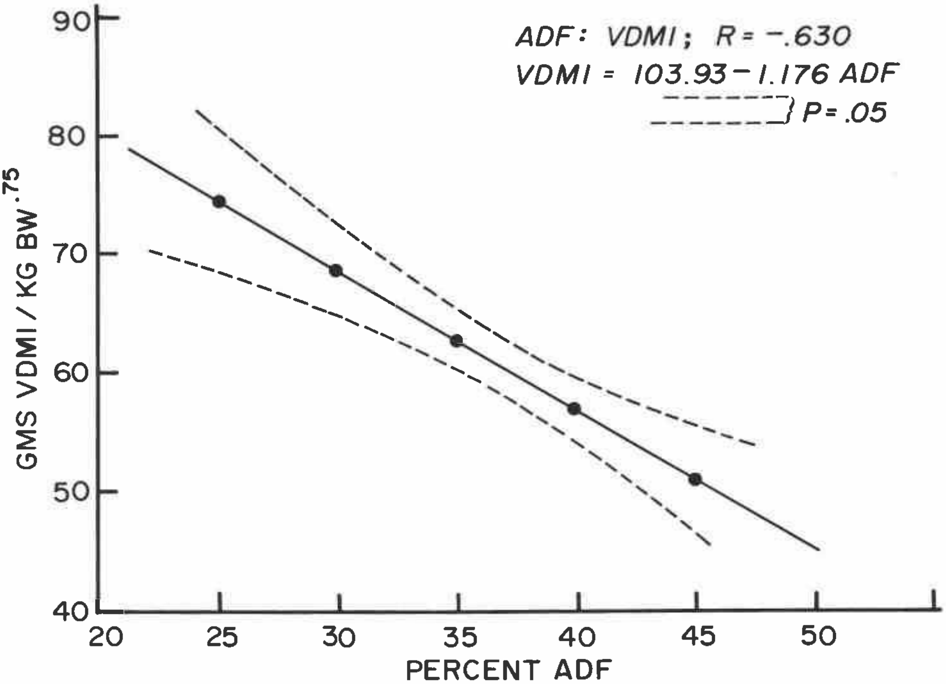

Figure 1. Estimates of mean voluntary dry matter intake (VDMI) and confidence intervals (P = 0.05) of alfalfa hays ranging in acid detergent fiber from 25 to 45 percent (from digestion trials using steers). Line was generated using linear equation in Table 3.

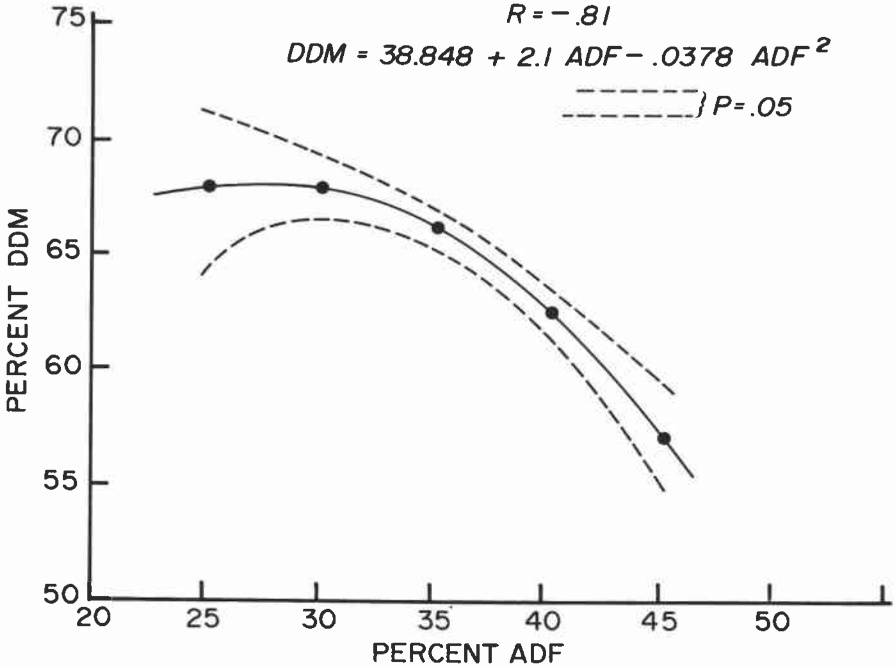

Figure 2. Estimates of mean digestible dry matter (DDM) with confidence intervals (P = 0.05) of alfalfa hay ranging in acid detergent fiber (ADF) from 25 to 40 percent (from digestion trials using steers). Curve was generated using the quadratic equation in Table 3.

DISCUSSION

The use of chemical analyses (CP, NDF, ADF) as predictors of hay quality depends upon these analyses being closely related to animal performance. Two important factors in animal nutrition are intake and digestibility. Previous experiments in other parts of the country have shown intake to be related to (or correlated with) NDF. However, this feeding study with steers indicated voluntary intake (VDMI) to be as closely related to ADF as to NDF. Digestibility in this study was also highly correlated with ADF.

Since both estimates of animal production (intake and digestibility) were highly correlated with ADF, it may be possible to predict intake and digestibility with only one fiber analysis: ADF. Prediction, however, requires that the shape of the relationship be determined. Mathematical analyses of the correlation between intake and ADF revealed that as fiber increased, intake decreased in a linear fashion. The correlation between digestibility and ADF was a bit more complicated. A curved line, or quadratic equation, was needed to best describe this relationship. This is because greater decreases in digestibility were found with higher concentrations of fiber.

By using both of these equations based upon ADF analysis, it will be possible to predict both intake and digestibility of alfalfa hay.

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III. Milk Production of Holstein Cows As Affected by Hay Quality

INTRODUCTION

Alfalfa hay quality is an important consideration when formulating dairy cow rations. Rations must contain high concentrations of crude protein (CP) and large quantities of digestible energy. These quality components can be measured by hay testing.

This experiment was conducted to determine the effect of hay quality on milk production and milk fat concentration when hay was fed as 30 and 45 percent of the ration. These are common ration formulations because 50 percent of the ration typically is fed as concentrate to achieve maximum milk production.

MATERIALS AND METHODS

Two production trials were conducted sequentially on 32 Holstein cows. Cows were selected based on three criteria:

1. The ability to produce at least 25 kilograms of milk per day (based on previous year's lactation records),
2. More than 40 days but less than 100 days postpartum, and
3. Second or later lactation.

A 4 x 4 Latin square design was used for each trial in which four lots of hay were used as treatment variables. Animals were placed into eight replications according to the number of days into lactation.

Trial 1

In the first trial, two Grade 2 and two Grade 3 hays (Table 1 of Research Report III) were fed as 30 percent of the dry matter of the total ration. All hays were grown in the Klamath Falls area, coarsely chopped, and stored under cover. Rations were formulated to contain a minimum of 15.5 percent CP, and the energy content varied only to the extent that the hays differed in energy (Table 2 of Report III).

Table 1. Chemical analysis, relative feed value, and grade of alfalfa hay lots in Trial 1†

Lot	CP	ADF	NDF	Ca	P	RFV	Grade
	%						
1	15.4	40.3	48.0	0.90	0.32	109	3 (low)
2	14.1	35.7	47.1	0.91	0.34	121	3 (high)
3	19.0	36.4	42.2	0.82	0.34	125	2 (low)
4	18.1	35.6	39.8	0.88	0.38	131	2 (high)

† CP = crude protein, ADF = acid detergent fiber, NDF = neutral detergent fiber, Ca = calcium, P = phosphorus, RFV = relative feed value.

Table 2. Ingredient composition and chemical analysis of rations used in Trial 1

	Ration			
Ingredient	1	2	3	4
	%			
Alfalfa hay	29.7	29.7	29.6	29.6
Corn silage	19.8	19.8	19.7	19.7
Barley, Pacific	20.2	20.2	21.8	21.8
Wheat, Pacific	20.2	20.2	21.8	21.8
Cottonseed meal, 44%	8.2	8.2	5.5	5.5
Urea	0.6	0.6	0.3	0.3
Salt	0.5	0.5	0.5	0.5
Dicalcium phosphate	0.1	0.1	0.2	0.2
Limestone	0.7	0.7	0.6	0.6
Chemical analysis				
Dry matter	55.5	52.7	56.1	52.4
Crude protein	15.8	15.2	16.0	15.5
Acid detergent fiber	27.1	24.6	22.8	23.6

Trial 1 rations contained 30 percent hay, 20 percent corn silage, and 50 percent concentrate (Table 2 of Report III). The amount of feed supplied daily was monitored to assure an excess of daily consumption. The amount fed was recorded daily and the amount refused was weighed once weekly. Fresh and weigh-back feed samples were dried and used to determine dry matter consumption.

The cows were milked in a double-four herringbone milking parlor twice daily. Milk was collected in calibrated Delaval jars and the weight was recorded. Milk samples were collected once weekly from two consecutive milkings and the composite was used to determine milk fat percentage.

Cows were weighed at the beginning of the trial and at the end of each feeding period. They were weighed immediately after the afternoon milking on two consecutive days, and the average was used to calculate average daily change in body weight for that period.

Four cows were chosen from each group for rumen volatile fatty acid analysis. Rumen fluid was drawn by a stomach tube and strained through cheesecloth; then 5 milliliters of fluid were added to 1 milliliter of 25 percent metaphosphoric acid in a polyethylene centrifuge tube. Samples were centrifuged at 173,000 relative centrifugal force for 30 minutes to separate solids. The supernatant was decanted into a small glass vial and capped until analysis. Volatile fatty acids were determined by using a stainless steel column (1/8 inch x 6 feet) packed with Chromosorb 100 in a Varian Aerograph Series 1200 gas chromatograph equipped with a flame ionization detector. Peak areas were automatically computed by a Spectra-Physics Minigrator™, and concentrations of acetate and propionate were expressed as micromoles per milliliter. Acetate:propionate ratios were than calculated for each cow and each feeding period.

Trial 2

Hays used in Trial 2 represented a wider range of neutral detergent fiber (NDF) and acid detergent fiber (ADF) and resulted in Grades of 1, 2, 3, and 4 for the four lots of hay (Table 3 of Report III). Procedures for the second trial were identical to those of the first, except that 45 percent of the ration was provided by hay, 5 percent by corn silage, and 50 percent by concentrate (Table 4 of Report III).

Table 3. Chemical analysis, relative feed value, and grade of alfalfa hay lots used in Trial 2†

Lot	CP	Ash	ADF	NDF	Ca	P	RFV	Grade
	%							
1	21.6	10.2	26.9	36.2	1.07	0.39	148	1
2	18.3	8.4	31.5	42.3	0.97	0.32	136	2
3	16.0	11.5	38.1	46.7	1.10	0.31	117	3
4	14.9	8.5	42.1	52.7	1.79	0.32	95	4

† CP = crude protein, ADF = acid detergent fiber, NDF = neutral detergent fiber, Ca = calcium, P = phosphorus, RFV = relative feed value.

Table 4. Ingredient composition and chemical analysis of rations used in Trial 2

Ingredient	Ration 1	Ration 2	Ration 3	Ration 4
	%			
Alfalfa hay	45	45	45	45
Corn silage	5	5	5	5
Molasses	2.5	2.5	2.5	2.5
Wheat, Pacific	---	---	39	39
Barley, Pacific	46	46	2.5	2.5
Dicalcium phosphate	0.5	0.5	0.5	0.5
Soybean meal	1	1	5.5	5.5
Chemical analysis				
Crude protein	16.7	15.6	16.2	15.7
Acid detergent fiber	19.5	21.5	23.8	26.3
Calcium	0.8	0.6	0.8	0.8
Phosphorus	0.4	0.4	0.4	0.4

RESULTS

Trial 1

No significant differences from the hays were observed in any of the production parameters (Table 5 of Report III). However, both rations containing the Grade 3 hays had higher levels of rumen propionate (Table 5 of Report III). The higher rumen propionate values were thus associated with the more fibrous hays. A high acetate:propionate ratio is often associated with high-level milk production. This suggests that if a higher percentage of the ration had been fed as hay, production differences from hay quality may have resulted.

Table 5. Production and physiological measurements from rations containing different quality hays (Trial 1)

Measurement	No. of observations	Ration 1	2	3	4	SE†	P
Actual milk yield (kg).........	32	25.5	25.1	25.6	25.7	0.51	0.26
Milk fat (%)....................	32	3.1	3.1	3.1	3.0	0.06	0.30
4% fat corrected milk (kg)....	32	22.2	21.8	21.9	21.9	0.32	0.10
Persistency (%)...............	32	99.1	98.0	97.7	98.8	0.50	0.16
Rumen volatile fatty acids:							
Acetate (umole/ml).........	16	46.1	46.1	43.8	48.5	1.7	0.28
Propionate (umole/ml)....	16	18.1[a]	17.6[a]	19.4[a]	23.0[b]	1.1	0.003
Acetate: propionate ratio..	16	2.8[a]	3.0[a]	2.4[b]	2.2[b]	0.1	0.001

† SE = standard error of mean of sample; P = probability. Mean values not followed by the same letter are significantly different (probability less than 0.05).

Trial 2

In the second trial, a higher proportion of the ration (45%) was fed as hay. Cows fed the ration containing Grade 1 hay produced more milk and were more persistent producers than cows fed rations containing lower quality hays. Cows fed the ration containing Grade 4 hay had the lowest production and were the least persistent producers. Cows fed the rations containing Grade 2 and Grade 3 hays were intermediate in both production and persistency and were not significantly different (Table 6 of Report III).

The fat content of the milk from cows fed rations containing Rations 1 and 3 was depressed compared to Rations 2 and 4 (Table 6 of Report III). The ADF of Ration 1 (19.5%) was below the 21 percent recommended by the National Research Committee (NRC) and may explain the reduced percentage of fat. The ration with Grade 3 hay, however, was 2.8 percent above the minimum recommended by NRC, which indicates that some additional factor resulted in the decreased milk content. The

Table 6. Production and physiological measurements from rations containing different quality hays (Trial 2)

Measurement	No. of observations	Ration 1	2	3	4	SE†	P
Avg. daily milk (kg)	32	30.2[a]	29.1[b]	30.0[b]	27.7[c]	0.9	0.001
Milk fat (%)	32	3.0[a]	3.2[b]	3.1[c]	3.2[b]	0.04	0.001
4% fat corrected milk (kg)	32	25.5	25.8	24.6	23.8	1.3	0.71
Persistency (%)	32	100.0[a]	97.9[b]	98.4[b]	96.2[c]	0.6	0.002
Dry matter intake (% body weight)	4	3.4[a]	3.4[a]	3.4[a]	3.1[b]	0.06	0.22
Body weight change per day (kg)	32	0.36	0.13	0.30	0.39	0.30	0.1
Rumen volatile fatty acids:							
Acetate (umole/ml)	16	56.8	48.6	62.9	57.2	2.57	0.28
Propionate (umole/ml)	16	30.1	24.8	24.9	31.1	3.99	0.36
Acetate: propionate ratio	16	2.1	2.4	2.1	2.2	0.13	0.57

† SE = standard error of mean of sample; P = probability. Mean values not followed by the same letter are significantly different (probability less than 0.05).

milk fat percentage of the cows was more directly related to the distribution of particle size of the hays than to any other ration characteristic measured.

Grade 1 hay, which caused the greatest fat depression, had the least amount of material retained on a 4.0 millimeter screen and the greatest quantity of material that passed through a 2.0 millimeter screen (Fig. 1 of Report III). To a lesser degree, Grade 3 hay (which caused a lesser milk fat depression) also contained a high proportion of fine material and a smaller amount retained by the 4.0 millimeter screen.

DISCUSSION

High-quality alfalfa hay is high in CP and low in NDF and ADF, resulting in high calculated values of RFV and TDN as previously described. This higher quality feed is recognized for its ability to produce more milk from dairy animals. However, results from Trial 1 indicated that the total ration must be considered in evaluating production. In this trial, only 30 percent of the ration was alfalfa hay, and the remainder was corn silage (20%) and concentrate (50%). Under these conditions, no differences in milk production were found between lots of hay.

When hays that differed more in quality were fed as 45 percent of the ration, however, production differences were observed. The highest quality hay (RFV 148, Grade 1) resulted in the greatest amount of milk produced. Excellent production also was obtained from the second highest quality hay (RFV 136, Grade 2). In fact, when expressed on a fat-

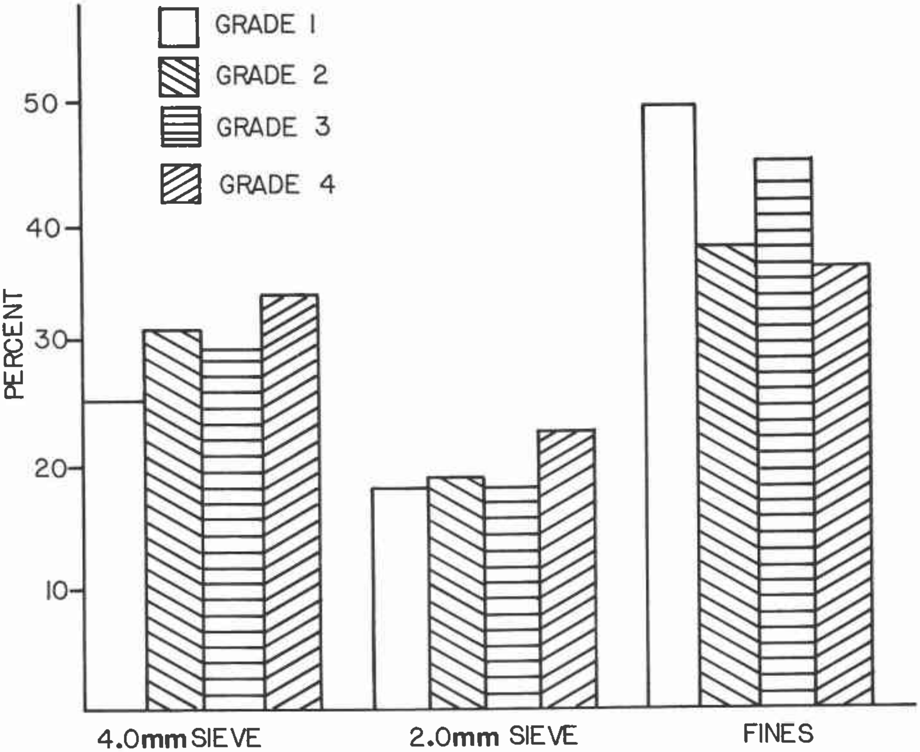

Figure 1. Distribution of particles of chopped alfalfa hay that were retained on a 4.0 mm and 2.0 mm Tylor Sieve and that passed through the 2.0 sieve (Fines) for four grades of hay (based on the relative feed value grading system).

corrected basis, production from the two highest quality hays was not significantly different.

These two milk production trials indicate that high levels of production can be obtained from high-quality alfalfa hay. The entire ration needs to be considered, however, to assure adequate levels of CP, ADF, Ca, and P. These components can be determined by forage analysis.

SUMMARY OF RESEARCH REPORTS

Research Report I

Alfalfa hay samples from five areas in Oregon were collected from 1977 to 1978. Crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), relative feed value (RFV), *in vitro* dry matter digestibility (IVDMD), calcium (Ca), and phosphorus (P) were assayed to determine the quality of the hay from each area at different times of the growing season.

Sample mean values for four of the five areas were within the range of 124 to 140 for RFV, presently designated as Grade 2 alfalfa hay. Similarly narrow ranges were obtained for CP (16.9 to 17.9%), IVDMD (65.3 to 66.1%), Ca (1.04 to 1.25%), and P (0.28 to 0.34%).

Significant geographical location differences were observed for Ca and ADF values. Ca values from District 1 (1.25%) were significantly higher than for District 4 (1.04%). Significantly lower ADF values from District 4 resulted in higher RFV's for this region. However, mean RFV's for all locations differed only 7 RFV units (124 to 131).

Significant differences in cutting dates were noted for CP, NDF, RFV, and Ca. Cutting 1 was significantly lower than Cutting 2 in CP but did not differ significantly from Cuttings 3 and 4. Cutting 2 was highest in RFV (133) as a result of low NDF values, but was significantly different only from Cutting 1 (128). Cutting 3 was highest in Ca (1.24%) and significantly higher than Cutting 1 (1.04%) but was not significantly different from Cuttings 2 and 4.

A high correlation ($r = 0.83$) was found between NDF and ADF. Both fiber analyses were negatively correlated with CP and IVDMD as expected, because both CP and IVDMD decrease with reduced hay quality, while fiber values increase.

These data indicate that the stage of maturity at cutting is of greater importance than the geographical location, year, or cuttings in determining hay quality. Results also emphasize the need for testing hay to assure high quality. The new standards for hay indicate that Grade 1 alfalfa hay (RFV greater than 140) can be obtained when cut in the late bud stage.

Research Report II

The performance of steers fed hays differing in quality was evaluated. Digestible dry matter (DDM) was as closely correlated with NDF as ADF ($r = -0.81$), indicating that either fiber analysis would be suitable for approximating digestibility of alfalfa hay for steers. Voluntary dry matter intake (VDMI) was more closely correlated with ADF than with NDF ($r = -0.63$ versus -0.51). This is in contrast to previously reported studies by Rohweder and others (1978). This may indicate a difference in hay grown in the different experimental areas, as temperature and day length have previously been reported as important factors in determining forage quality characteristics (Van Soest et al., 1978).

Regression equations were developed in which ADF was used to predict both DDM and VDMI of hays grown in the high elevation area of the Klamath Basin; $DDM = 38.85 + 2.1(ADF) - 0.038\,(ADF^2)$; and $VDMI = 103.93 - 1.18(ADF)$.

Milk production from dairy cows fed Grade 2 and Grade 3 as 30 percent of their ration was not significantly different. However, differences were noted in the acetate:propionate ratio.

When hays of Grades 1 to 4 were fed as 45 percent of the ration, significant production differences were observed. Cows fed the ration containing the highest quality hay produced more milk and were more persistent producers than the cows fed lower quality hays. Howver, milk fat content was depressed almost 8 percent when Grade 1 hay was fed as part of a 19.5 percent ADF ration. When milk production was expressed as 5 percent fat corrected milk, there was no significant production difference in rations containing Grade 1 and Grade 2 hays. This indicates that low fiber rations (less than 21% ADF or 17% MCF) may result in depressed milk fat production.

CONCLUSIONS OF RESEARCH REPORTS

1. High-quality alfalfa hay can be grown in all alfalfa-producing regions of Oregon in all cuttings throughout the year.
2. Good management practices (harvesting at early flower, proper handling of hay during baling and storage) are more important in determining the quality of alfalfa hay than geographical region or cutting during the season.
3. Hay samples used in Research Report I showed a narrow range of values for chemical analyses probably because a large number of samples came from experienced hay growers.
4. Buying hay from a particular region or from a particular cutting will not assure high quality. Hay testing is the only sure objective measure of quality.
5. Both intake (VDMI) and digestibility (DDM) were highly correlated with ADF. This suggests that ADF may be an adequate measure of forage fiber. Crude protein analysis will also be necessary, however, to adequately evaluate hay quality for ration formulation.
6. Milk production did not differ significantly from cows fed rations containing 30 percent alfalfa hay that ranged from 109 to 131 RFV (Grades 2 and 3).
7. Milk production did differ significantly when cows were fed rations containing 45 percent alfalfa hay. Production was greatest from highest quality hays (RFV 148 and 136).
8. Total ration analysis is necessary for both fiber (ADF) and CP to determine the most economical grade of alfalfa to use in the ration.

FUTURE DIRECTION OF HAY QUALITY RESEARCH

A number of aspects of alfalfa quality and testing should be addressed by research and Extension efforts. Not all of these will be possible at OSU because of limitations of facilities and finance. However, the articulation of these needs will help shape the direction of efforts in hay testing, an area of importance to Oregon agriculture.

OBJECTIVES

1. Develop better and more rapid laboratory analyses in which alfalfa growers and livestock operators will have more confidence;

2. Develop correlations between different forage tests to allow more effective interstate transport of hay;

3. Increase coordination of efforts between hay grower and livestock production organizations;

4. Increase coordination between Pacific Northwest forage and livestock production programs; and

5. Increase public understanding of factors affecting forage and hay quality and of laboratory analyses used to measure quality characteristics.