PROPOSED HAY GRADING STANDARDS BASED ON LABORATORY ANALYSES FOR EVALUATING QUALITY[1]

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SUMMARY

This paper constitutes a report from the Forage Analysis Subcommittee of the Hay Marketing Task Force organized by the American Forage and Grassland Council and presents a proposal for the establishment of market hay grades. The need for hay standards that will more adequately express feed value in forages and that will communicate this value among agricultural scientists, agri-business clientele, and producers has long been recognized world wide. The Forage Analysis Subcommittee surveyed United States scientists working with forage quality and animal nutrition to obtain a concensus of opinion relative to more precise techniques for evaluating forage quality. Subsequently, research data were collected on forage samples from widely differing climates in the United States. Samples included the following species: alfalfa – *Medicago sativa* L.; smooth bromegrass – *Bromis inermis* Leyss.; orchardgrass – *Dactylis glomerata* L.; reed canarygrass – *Phalaris arundinacea* L.; tall fescue – *Festuca arundinacea* Schreb.; 'Pangola' digitgrass – *Digitaria decumbens* Stent.; bahiagrass – *Paspalum notatum* Flügge; and 'Suwannee' bermudagrass – *Cynodon Dactylon* (L.) Pers. The relationships of acid detergent fiber with *in vivo* digestible dry matter and neutral detergent fiber with dry matter intake are reported. A relative feed value based upon digestible dry matter intake as an estimate of digestible energy intake is proposed for evaluation of all forages. Five hay grades and one sample grade[3] for all legumes and grasses are proposed by the committee.

Key Words: Acid Detergent Fiber, Forage Quality, Infrared Reflectance, Market Hay Grades, Neutral Detergent Fiber, Relative Feed Value.)

INTRODUCTION

Hay is one of North America's most widely grown crops. Nearly 62 million acres of hay were harvested in 1975 with production of more than 131 million tons and values in excess of $6.5 billion. Yet, buying and selling hay is still largely a "guessing" game. Less than 1% of the hay crop is federally graded, and most of the 27 million tons of hay marketed each year in the United States is purchased on trust between buyer and seller.

Present United States hay grades depend on visual examination only, and there is often little relationship from place to place between price and visual measurements of quality such as leafiness, steminess and color. Even the majority of farmers and ranchers who grow and use most of their hay need better guidelines as to its true nutrient value. The eye and nose cannot always detect the quality differences that effect rate of gain or milk production.

HAY MARKETING TASK FORCE

In 1972 the American Forage and Grassland Council (AFGC) formed a Hay Marketing Task Force to: a) identify hay marketing problems, b) determine problem priorities and possible practical solutions, and c) develop specific recommendations for action. A Forage Analysis Subcommittee was charged with establishing a system for pricing hay based on some realistic measurements of feed value. Numerous reports have been prepared and talks presented based on the Subcommittee's findings. (Barnes, 1975, Barnes *et al.*, 1977; Moore *et al.*, 1975; Rohweder *et al.*, 1976a,b,c).

In 1974 the Forage Analysis Subcommittee surveyed United States scientists working with forage quality and animal nutrition to obtain a

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[3] See tables 7 and 8.

concensus of opinion relative to more precise techniques for evaluating forage quality. Three basic methods of estimating *in vivo* digestibility are in use today: 1) the digestion trial – which is a direct and accurate method of analyzing material consumed and excreted by a test animal but which is lengthy and costly; 2) the *in vitro* rumen fermentation technique; and 3) newer chemical methods which more adequately characterize the constituents in feeds.

Most scientists working with forage quality and livestock nutrition believed that data from the *in vitro* technique most closely approximates energy availability or digestibility in forages as measured *in vivo*. The two-stage *in vitro* rumen fermentation technique (Tilley and Terry, 1973) has been shown to be superior to other *in vitro* systems; however, it is doubtful the technique will become widely adopted for routing use.

Many chemical assays have been proposed to estimate herbage quality and its relationships to animal performance. The majority of the respondents indicated that the acid-detergent fiber (ADF) and neutral-detergent fiber (NDF) analyses proposed by Van Soest (Barnes, 1973; Goering and Van Soest, 1970) were the chemical assays of choice to estimate *in vivo* dry matter digestibility and dry matter intake, respectively. This analytical system divides the organic matter of plants into cell walls and cell contents through the use of detergents, table 1. The nutritional availability of cell contents is almost complete, averaging 98%. Fraction A (cell contents) includes substances for which digestive enzymes exist in the digestive tracts of all animals. Fraction B (cell walls) include substances that are digested to a significant extent only in animal species possessing important gastrointestinal fermentation capabilities. The cell wall portion of a forage affects the volume a feed will occupy in the digestive tract, a principal factor limiting consumption by animals.

Forages such as tropical grasses and very mature forages are high in non-digestible components which in turn affect digestibility of other components to the point that animals have difficulty obtaining adequate nourishment from the amount they are physically able to consume. Animals fed such forage are often unable to produce milk or gain weight economically.

The Forage Analysis Subcommittee subsequently obtained forage samples with known analytical data from a number of locations to determine the precision of the above relationships. Data, including acid-detergent fiber and neutral-detergent fiber analyses, as well as *in vivo* digestible dry matter and dry matter intake measurements were obtained from Wisconsin, Indiana, Pennsylvania and Florida (Barnes, 1975[4]; Krueger, 1967; Lema, 1972; Moore *et al.*, 1970; Moore, 1975; Ventura *et al.*, 1975). Species included were: alfalfa – *Medicago sativa* L.; smooth bromegrass – *Bromis inermis* Leyss.; orchardgrass – *Dactylis glomerata* L.; reed canarygrass – *Phalaris arundinacea* L.; tall fescue – *Festuca arundinacea* Schreb.; 'Pangola' digitgrass – *Digitaria decumbens* Stent.; bahiagrass *Paspalum notatum* Flügge; and 'Suwannee' bermudagrass – *Cynodon dactylon* (F.) Pers. The relationships of acid-detergent fiber to *in vivo* digestible dry matter (DDM) and neutral-detergent fiber to dry matter intake (DMI) were estimated by regression analysis. F-tests were used to test the significance of each component in the equations.

Hay grades for legumes, legume-grass mixtures, and grasses based on organoleptic[5] characteristics including maturity, percent leaves (Lee and Smith, 1972; Smith, 1973; Walters, 1971), color, percent foreign material, and freedom from damage are proposed. Typical chemical concentration and animal performance characteristics for each grade are listed. A digestible dry matter intake (DDMI) value as an estimate of digestible energy intake (DEI) is proposed. The digestible dry matter intake concept differs from the Nutritive Value Index proposed by Crampton *et al.* (1960) in that it is not based on a standard forage. Values in this paper express actual intake of digestible dry matter by sheep and are highly correlated with digestible energy intake.

RESULTS AND DISCUSSION

The concentrations of acid-detergent fiber and neutral-detergent fiber in alfalfa grown in Florida are comparable to the concentrations for each factor in alfalfa grown in Wisconsin, Indiana, Pennsylvania at similar stages of maturity, table 2. However, the crude protein (CP)

[4] Barnes, R. F. 1975. *Private communication*, AR 66, p 38–40.

[5] Organoleptic is defined as affecting or making an impression upon one or more organs of special sense and used in subjective testing; i.e., sight, feel, odor, flavor.

TABLE 1. DIVISION OF FORAGE ORGANIC MATTER BY THE SYSTEM OF ANALYSIS USING DETERGENTS[a]

		Nutritional availability	
Fraction	Components	Ruminant	Non-ruminant
A. Cell contents	Lipids	Virtually complete	Highly available
(Soluble in neutral-detergent)	Sugars	Virtually complete	Highly available
	Organic acids and water	Virtually complete	Highly available
	Soluble matter	Virtually complete	Highly available
	Starch	Virtually complete	Highly available
	Non-protein nitrogen	Virtually complete	Highly available
	Soluble protein	Virtually complete	Highly available
	Pectin	Virtually complete	Highly available
B. Cell walls			
(Fiber insoluble in neutral-detergent-NDF)			
(1) Soluble in acid-detergent	Hemicellulose	Partial	Very low
(2) Insoluble in acid-detergent (Acid-Detergent Fiber-ADF)	Cellulose	Partial	Very low
	Lignin	Indigestible	Indigestible
	Lignified N compounds	Indigestible	Indigestible
	Heat damaged protein	Indigestible	Indigestible
	Keratin	Indigestible	Indigestible
	Silica	Indigestible	Indigestible

[a]Jorgensen, 1971.

TABLE 2. TYPICAL CHEMICAL COMPOSITION OF CRUDE PROTEIN (CP), ACID-DETERGENT FIBER (ADF), AND NEUTRAL-DETERGENT FIBER (NDF) IN ALFALFA, TEMPERATE GRASSES, AND SUBTROPICAL GRASSES GROWN IN FLORIDA, INDIANA, PENNSYLVANIA AND WISCONSIN

	North			South		
Species and maturity	CP	ADF	NDF	CP	ADF	NDF
A. Alfalfa						
1. Bud-first flower	>19	<31	<40	25-30	30-32	33-41
2. F.F.-mid-bloom	17-19	13-35	40-46	19-27	34-37	40-47
3. Mid-full bloom	13-16	36-41	46-51	22	35	42
4. Post bloom+	<13	>41	>51	17-18	37-41	>51
B. Grasses[a]						
2. Veg-Boot[b]	>18	<33	<55	18-19	32-33	64-69
3. Boot-early head[c]	13-18	34-38	55-60	8-18	34-40	64-79
4. Head-milk[d]	8-12	39-41	61-65	6-11	39-43	70-80
5. Dough+[e]	<8	>41	>65	4-9	39-47	71-81

[a]North—Smooth bromegrass, orchardgrass, reed canarygrass and tall fescue.

[b]Subtropical—'Pangola' digitgrass and bermudagrass—2 to 3 weeks.

[c]Subtropical—Bahiagrass—2 weeks; 'Pangola' digitgrass and bermudagrass—4 to 6 weeks.

[d]Subtropical—Bahiagrass—4 to 6 weeks; 'Pangola' digitgrass and bermudagrass—8 weeks.

[e]Subtropical—All 10 weeks.

concentration was higher in alfalfa grown in Florida at all stages of maturity. Crude protein and acid detergent fiber concentrations in temperate and subtropical grass species are comparable at selected stages of maturity or age; however, neutral-detergent fiber concentrations in subtropical grasses are higher than in temperate grasses. It appears that this difference is primarily due to increased hemicellulose concentration in the subtropical species, table 3 (Moore and Mott, 1973).

Crude protein concentration is correlated with dry matter digestibility and with its own digestibility in legumes; however, crude protein concentration does not satisfactorily estimate digestibility in grasses (Lema, 1972; Marten *et al.*, 1975). Crude protein concentration also may not satisfactorily estimate digestibility of legumes and grasses when grown across a broad range of climatic conditions. Studies conducted in Wisconsin and Minnesota (Marten, 1970; Smith, 1969, 1970, 1975; Vough and Marten, 1971) showed that crude protein concentrations in alfalfa, timothy, and oats increased at warmer temperatures while dry matter digestibility remained constant.

TABLE 3. CONCENTRATION OF CRUDE FIBER (CF), NEUTRAL-DETERGENT FIBER (NDF), ACID-DETERGENT FIBER (ADF), HEMICELLULOSE, AND LIGNIN IN TEMPERATE AND TROPICAL GRASS SPECIES—PERCENT[a]

Species	CF	NDF	ADF	Hemicellulose[b]	Lignin
Temperate					
Avg	25.8-34.8	50.1-66.6	27.6-38.3	22.5-28.3	2.8-6.4
Overall	18-40	34-73	18-46	16-27	1-11
Tropical					
Avg	28.5-35.6	61.4-74.6	31.7-40.7	29.7-33.9	3.3-6.7
Overall	18-47	45-85	21-57	24-28	2-11.5

[a]Moore and Mott, 1973.

[b]Difference between neutral-detergent fiber and acid-detergent fiber (NDF-ADF).

Digestible Dry Matter. Acid-detergent fiber is the assay of choice to estimate digestibility and the analysis often indicates the digestibility of cell walls as well as cell solubles. Acid-detergent fiber concentration is highly correlated with *in vivo* digestible dry matter in alfalfa, temperate grasses, and subtropical grasses. Measurement of this correlation in several trials is shown in table 4.

Equations derived from the data summarized in table 2 for predicting *in vivo* digestible dry matter from acid-detergent fiber concentration as developed from regression analyses are shown in table 5. In all cases the use of curvilinear regression equations improved the prediction of *in vivo* digestible dry matter compared to simple linear regressions.

Results from this study are confirmed by trials conducted in Wisconsin and Minnesota. Lema (1972) showed that acid-detergent fiber may not improve the ability to predict *in vivo* digestible dry matter in pure legume forages (ADF: r = –.83 CP: r = .82); however, it markedly improved the ability to estimate digestibility in grasses (ADF: r = –.93, CP: r = .77). Marten *et al.* (1975) in Minnesota showed that acid detergent fiber was the best chemical predictor of *in vivo* digestible dry matter in corn and sorghum silages, r = –.78 and r = –.89, respectively.

Dry Matter Intake. Neutral-detergent fiber is the chemical assay of choice to estimate voluntary intake. Neutral-detergent fiber concentration has the highest correlation with voluntary intake of forages, which is a function of the rate of digestion, which in turn influences the rate of passage and ultimately the amount of forage the animal can consume.

The correlation of neutral-detergent fiber concentration with dry matter intake ranged from r = –.32 to r = –.94 table 4, and varied with species and location. In general, the correlation was lower with subtropical species compared to temperate species. This correlation was improved by combining locations, but the correlation decreased when bahiagrass and 'Suwannee' bermudagrass were included. Data from Lowery *et al.* (1968) indicates that *in vivo* digestible dry matter and dry matter intake for Coastcross I bermudagrass are higher than for either 'Coastal' bermudagrass and 'Suwannee' bermudagrass. Therefore, the relationship in table 4 may be changed as additional data are included. This relationship is now being studied.

Equations derived from the data summarized in table 2 for predicting dry matter intake from neutral-detergent fiber concentration are shown in table 5. The use of curvilinear regression equations also improved the ability to predict dry matter intake in all forages compared to simple linear equations except when 'Suwannee' bermudagrass was included. These correlation values are in line with data published by British scientists (Jones and Bailey, 1974; Jones and Walters, 1978; Osbourn *et al.*, 1970). Additional data on temperate and subtropical species is needed to evaluate this relationship across a broader range of species, varieties, and growing conditions.

Further Analysis of Data. Subsequent to the

TABLE 4. CORRELATION (R) OF ACID-DETERGENT FIBER (ADF) WITH DIGESTIBLE DRY MATTER (DDM) AND NEUTRAL-DETERGENT FIBER (NDF) WITH DRY MATTER INTAKE (DMI) FROM SEVERAL TRIALS CONDUCTED IN THE U.S.

Species	Location	ADF:DDM	NDF:DMI
Alfalfa	Wisconsin	R = -.83	R = -.48
	Wisconsin, Indiana, Pennsylvania	-.84	-.75
	Florida	-.91	-.44
	Combined	-.82	-.62
Grasses[a]	Wisconsin	-.93	-.46
Grasses[b]	Wisconsin, Indiana, Pennsylvania	-.73	-.94
Bahiagrass	Florida	-.90	-.32
'Pangola' digitgrass	Florida	-.92	-.92
Bermudagrass	Florida	-.87	-.47
Grasses[c]	Combined	-.76	-.76

[a]Smooth bromegrass, orchardgrass, and reed canarygrass.

[b]Smooth bromegrass, orchardgrass, reed canarygrass, and tall fescue.

[c]Smooth bromegrass, orchardgrass, reed canarygrass, tall fescue, 'Pangola'-digitgrass, and bahiagrass.

TABLE 5. REGRESSION EQUATIONS FOR PREDICTING *IN VIVO* DIGESTIBLE DRY MATTER (DDM) FROM ACID-DETERGENT FIBER (ADF) AND DRY MATTER INTAKE (DMI) FROM NEUTRAL-DETERGENT FIBER (NDF), CORRELATION VALUES (R) AND STANDARD DEVIATION (SD) VALUES FOR ALFALFA, TEMPERATE GRASSES AND SUBTROPICAL GRASSES

Description		R^2 (%)	R	SD[a]
1. *In vivo* digestible dry matter (DDM)				
a. Alfalfa n = 40				
North only	DDM = 71.1 + .593 ADF% − .0221 ADF%^{2}	71	.84	3.61
North and South	DDM = 65.5 + .975 ADF% − .0277 ADF%^{2}	68	.82	3.50
b. Grasses				
Temperate	DDM = 41.9 + 2.15 ADF% − .0433 ADF%^{2}	53	.73	4.98
With aftermath	DDM = 49.7 + 1.67 ADF% − .0364 ADF%^{2}	46	.68	5.23
With pangolagrass	DDM = 44 + 2.01 ADF% − .0412 ADF%^{2}	49	.70	4.96
With bahiagrass	DDM = 34.8 + 2.56 ADF% − .0491 ADF%^{2}	58	.76	4.81
With bermudagrass[b]	DDM = 59.2 + 1.32 ADF% − .0338 ADF%^{2}	48	.69	5.74
2. Dry matter intake (DMI)				
a. Alfalfa				
North only	DMI = 86.7 + .425 NDF% − .0164 NDF%^{2}	56	.75	6.13
North and South	DMI = 39 + 2.68 NDF% − .0410 NDF%^{2}	39	.62	7.95
b. Grasses				
Temperate	DMI = 95.3 + 6.70 NDF% − .0668 NDF%^{2}	89	.94	3.04
With aftermath	DMI = 118 + 7.41 NDF% − .0723 NDF%^{2}	56	.75	6.79
With pangolagrass	DMI = 92.5 + 6.39 NDF% − .0623 NDF%^{2}	64	.80	6.75
With bahiagrass	DMI = 54.8 + 1.22 NDF% − .0176 NDF%^{2}	58	.76	7.64
With bermudagrass	DMI = 123 + 1.22 NDF% − .00385 NDF%^{2}	35	.59	8.71

[a]Standard deviation from regression.

[b]'Suwannee' bermudagrass.

original analysis by the Subcommittee, data have been obtained on 19 species and mixtures from 12 states. Intake information also has been obtained for cattle. The analysis of these data is not complete; however, analyses on this expanded sample confirms the relationships reported in this paper. Single assays appear to do as well as combinations of assays in predicting digestible dry matter and dry matter intake. Dry matter percentage combined with neutral-detergent fiber appears to improve the ability to predict dry matter intake. This observation needs further study.

Digestible Dry Matter Intake. Both digestible energy concentration and voluntary intake of digestible energy should be considered when assigning the "optimum" feeding value to a hay or silage. Analyzing for digestible dry matter intake can provide more effective guidelines that will lead to higher production and gain, more efficient use of feeds, lower costs, and greater profits. The analyses also can serve as effective means for evaluating and pricing hay.

It has been proposed that the acid-detergent fiber analysis more adequately evaluates *in vivo* digestible dry matter and energy availability in forages than other chemical assays. The neutral-detergent fiber analysis provides the best indication of dry matter intake for legumes and grasses by the animal. A combination of both analyses can provide an estimate of digestible dry matter intake for a forage as follows:

DDM (%) is inversely related to ADF concentration, i.e., DDM decreases as ADF increases.

DMI ($g/kgW^{.75}$) is inversely related to NDF concentration, i.e., DMI decreases as NDF increases.

DDMI ($g/kgW^{.75}$) is a function of $\frac{DDM \times DMI}{100}$

Application of Fiber Analyses and Digestible Dry Matter Intake to Hay Marketing. Hay is big business in the United States with nearly 131 million tons produced annually. Twenty percent or 27 million tons are sold off the producing units as cash hay. Wide variations in the percentage sold as cash hay exists among states. For example, in Arizona and California, 78 and 74%, respectively, of all hay produced was sold off the form where produced; while Wisconsin, the largest hay producer with 10.6 million tons, sells only 8% off the farm.

Nine states have indicated that a hay marketing program is in some stage of development; however, California is the only state with a system based on chemical evaluation. Hay inspections nationally are based on the federal hay grade standards set forth in the Agricultural Marketing Act of 1946. In 1975 less than 300 inspections were made nationwide. While the federal hay grades reflect quality differences, they are not based on quantitative measurements. There is a need to develop hay grades that more precisely reflect feed value.

The new hay standards proposed by The Forage Analysis Subcommittee are described in tables 6, 7 and 8. Legumes, grasses, and legume-grass mixtures are evaluated on a continuum permitting a calculation of feeding value for all types of plants. Both organoleptic characteristics and representative chemical analyses are used to establish five grades with one sample grade. The grades are based on advancing stages of maturity and are designed to represent measurable differences in animal response.

The knowledge that the intake potential for hay can be just as important as digestibility led to a combination of these two factors to give an estimate of digestible dry matter intake or relative feed value. It is an expression of overall forage quality and estimates the relative intake of digestible energy when forage is the only source of dietary energy and protein. The formulas used to calculate relative feed value are presented in table 6. They were derived from regression analyses of intake and digestibility of dry matter data for forages of known composition that were fed to sheep, table 5. The relative feed value is calculated by dividing the estimated digestible dry matter by 40 times 100 to provide a common base across all possible forages. This establishes full bloom legumes as the base hay. These values indicate that the best pure grass hays appear to grade no higher than Grade 2 relative to legume hays with mature grass hays grading as low as Grade 5. Relative feed values range from over 140% for early cut legumes to less than 83% for mature grass hays. Assuming a base price of $60 per short tonne for mature legumes (Grade 4), hay prices would range from over $85 per short tonne to less than $50 per short tonne.

The proposed grades are described by the representative stage of maturity; leafiness; color; amount of foreign material; freedom from mold, musty odor, dust, and other damage; typical chemical composition values for crude protein, acid-detergent fiber, and neutral-detergent fiber; and relative feed values. Typical values for legumes and predominantly legume mixtures are presented in table 7 and for grasses and predominantly grass mixtures in table 8.

Computerized Analytical and Ration Balancing Programs. Hay dealers report that much of their hay is purchased one day and sold the next. Time does not allow them to obtain a laboratory analysis to estimate forage quality. Therefore, most hay that is sold is not evaluated properly unless done so by the producer. Recently, Norris *et al.* (1976) reported the development of a near-infrared reflectance technique for the rapid prediction of forage composition and animal responses to forages. It is proposed by Shenk *et al.* (1976) that remote infrared reflectance instruments placed at strategic locations (hay marketing centers, feed stores, extension offices, etc.) can be attached to a computer network system. These remote instruments would be small and simple to operate with the capability of analyzing a hay sample for moisture, crude protein, acid-detergent fiber, and neutral-detergent fiber and predicting relative feed value. The procedure would begin by taking a core sample from a lot of hay, grinding it in a small grinder, and placing the forage in an appropriate sample holder on the remote instrument. The central computer, via telephone, would reall from memory the appropriate calibration curves for the specific remote instrument involved, since these may differ from one instrument to another. As a safeguard to insure proper instrument operation, the remote instrument operator would visually estimate the hay quality by indicating a number 1 to 6, corresponding to the proposed hay marketing standards, on the remote instrument. This would serve as a guide to the range of each chemical constituent to be obtained from the sample. Then the reflectance data would be collected automatically from the sample, analyzed by the central computer, and the chemical component of the hay displayed on the remote instrument. The time involved for analyzing should not exceed two minutes. If the chemical composition does not accurately compare with the visual grade given by the remote instrument operator, the warning light would flash indicating the sample should be rerun to make sure the remote instrument is not in error. This system could be used anywhere a suitable telephone outlet can be obtained. Considerable developmental and educational work remains to be

TABLE 6. TYPICAL DIGESTIBLE DRY MATTER (DMM), DRY MATTER INTAKE (DMI) AND DIGESTIBLE DRY MATTER INTAKE (DDMI) VALUES FOR PROPOSED MARKET HAY GRADES DESCRIBED IN TABLES 7 AND 8[a]

Grade	Legume hays			Grass hays			Relative feed value
	In vivo DDM %	DMI g/W kg$^{.75}$	DDMI g/W kg$^{.75}$	*In vivo* DDM %	DMI g/W kg$^{.75}$	DDMI g/W kg$^{.75}$	%[b]
1.	>70	>80	>57	...	...	...	>140
2.	66-70	75-80	50-57	>72	>69	>49	124-140
3.	58-65	68-74	41-49	62-72	65-69	41-49	101-123
4.	<58	<68	<41	55-61	59-64	33-40	83-100
5.	...	...	...	<55	<59	<33	<83

[a]Formulas used to calculate relative feed value: legume—DDM = 65.5 + .975 ADF% - .0277 ADF%^{2}; DMI = 39 + 2.68 NDF% - .0410 NDF%^{2}; grasses—DDM = 34.8 + 2.56 ADF% - .0491 ADF%^{2}; DMI = 54.8 + 1.22 NDF% - .0176 NDF%^{2}; DDMI = DDM × DMI/100; relative feed value = DDMI × 2.5; where DDM = *In vivo* digestible dry matter; DMI = dry matter intake; DDMI = digestible dry matter intake.

[b]Relative feed value is an estimate of overall forage quality. It is calculated from intake and digestibility of dry matter when forages of known composition were fed to sheep. The values are relative; however, they are equally appropriate for all classes of livestock. Relative feed value estimates the intake of digestible energy when the forage is the only source of dietary energy and protein.

TABLE 7. PROPOSED MARKET HAY GRADES FOR LEGUMES AND LEGUME-MIXTURES (HAY MARKETING TASK FORCE)

Grade	Stage of maturity international term	Definition	Physical description	Typical chemical composition—%[a]			Relative feed value
				CP[d]	ADF	NDF	
				(%)			
1. Legume Hay	Pre bloom	Bud to first flower; stage at which stems are beginning to elongate to just before blooming.	40 to 50% leaves[b]; green; less than 5% foreign material; free of mold, musty odor, dust, etc.	>19	<31	<40	>140
2. Legume Hay	Early bloom	Early to mid bloom; stage between initiation of bloom and stage in which ½ of the plants are in bloom.	35 to 45% leaves[b]; light green to green; less than 10% foreign material; free of mold, musty odor, dust, etc.	17-19	31-35	40-46	124-140
3. Legume Hay	Mid bloom	Mid to full bloom; stage in which ½ or more of plants are in bloom.	25 to 40% leaves[b]; yellow green to green; less than 15% foreign material; free of mold, musty odor, dust, etc.	13-16	36-41	47-51	101-123
4. Legume	Full	Full bloom and beyond.	Less than 30% leaves[b]; brown to green; less than 20% foreign material; free of musty odor, etc.	<13	>41	>51	≤100

6. Sample grade[c]
Hay which contains more than a trace of injurious foreign material (toxic or noxious weeds and hardware) or that definitely has objectionable odor or is under cured, heat damaged, hot, wet, musty, moldy, caked, badly broken, badly weathered or stained, extremely overripe, dusty, which is definitely low quality or contains more than 20% foreign material or more than 20% moisture.

[a]Chemical analyses expressed on dry matter basis. Chemical concentrations based on research data from NC and NE states and Florida. Dry matter (moisture) concentration can affect market quality. Suggested moisture levels are: grades 1 and 2 <14%, grade 3 <18%, and grade 4 <20%.

[b]Proportion by weight.

[c]Slight evidence of any factor will lower a lot of hay by one grade.

[d]CP = crude protein; ADF = acid detergent fiber; NDF = neutral detergent fiber; relative feed value is based on digestible dry matter intake. See table 6.

TABLE 8. PROPOSED MARKET HAY GRADES FOR GRASSES AND GRASS-LEGUME MIXTURES (HAY MARKETING TASK FORCE)

Grade	Stage of maturity international term	Definition	Physical description	Typical chemical composition—%[a]			Relative feed value
				CP[bg]	ADF	NDF[c]	
				(%)			
2. Grass Hay	Pre head	Late vegetative to early boot; stage at which stems are beginning to elongate to just before heading; 2 to 3 weeks' growth.[e]	50% or more leaves[d]; green; less than 5% foreign material; free of mold, musty odor, dust, etc.	>18	<33	<55	124-140
3. Grass Hay	Early head	Boot to early head; stage between late boot where inflorescence is just emerging until the stage in which ½ inflorescences are in anthesis; 4 to 6 weeks' growth[e].	40% or more leaves[d]; light green to green; less than 10% foreign material; free of mold, musty odor, dust, etc.	13-18	33-38	55-60	101-123
4. Grass Hay	Head	Head to milk; stage in which ½ or more of inflorescences are in anthesis and the stage in which seed are well formed but soft and immature; 7 to 9 weeks' regrowth[e].	30% or more leaves[d]; yellow green to green; less than 15% foreign material; free of mold, musty odor, dust, etc.	8-12	39-41	61-65	83-100
5. Grass Hay	Post head	Dough to seed; stage in which seeds are of dough-like consistency until stage when plants are normally harvested for seed; more than 10 weeks' growth[e].	20% or more leaves[d]; brown to green; less than 20% foreign material; slightly musty odor, dust, etc.	<8	>41	>65	<83

6. Sample grade[f]

Hay which contains *more than a trace of injurious foreign material* (toxic or noxious weeds and hardware) or that definitely has objectionable odor or is under cured, heat damaged, hot, wet, musty, moldy, caked, badly broken, badly weathered or strained, extremely overripe, dusty, which is distinctly low quality, or contains more than 20% foreign material or more than 20% moisture.

[a]Chemical analyses expressed on dry matter basis. Chemical concentrations based on research data from NC and NE states and Florida. Dry matter (moisture) concentration can affect market quality. Suggested moisture levels are: grade 2 <14%, grade 3 <18%, and grades 4 and 5 <20%.

[b]*Fertilization with nitrogen may increase CP concentration in each grade* by up to 40%.

[c]Tropical grasses may have higher NDF concentrations than indicated in this table.

[d]Proportion by weight.

[e]For grasses that do not flower or for which flowering is indeterminant.

[f]Slight evidence of any factor will lower a lot of hay by one grade, except grade 5.

[g]CP = crude protein; ADF = acid detergent fiber; NDF = neutral detergent fiber; relative feed value is based on digestible dry matter intake. See table 6.

done to perfect this system as described.

Such a computerized system also provides the opportunity to enter the data automatically into ration balancing and production accounting systems such as Dairy Herd Improvement. With increasing necessity to improve feed efficiency in livestock, the digestible dry matter intake concept offers new opportunities to provide not only an indication of nutritive value but also a value for intake. In some systems it will take a small amount of effort to program in the new information. In others it may be more difficult. However, additional information is needed to perfect the concept. Properly described forage samples with known crude protein, acid-detergent fiber, neutral-detergent fiber, and *in vivo* digestible dry matter and dry matter intake are urgently needed.

CONCLUSIONS

1. The digestible dry matter intake technique described offers new opportunities in forage and feed evaluation. It provides a more precise evaluation of the feed value of forage. A measure of intake also is provided.

2. The technique has immediate application in more effective grading and pricing of market hay. Legume, legume-grass mixtures, and grass hays can be evaluated and priced on one continuum.

3. The technique also offers new opportunities in computerized ration balancing programs.

4. However, the technique is in an evolutionary state. The committee has developed the technique with a limited number (350) of samples on eight species from four states in diverse climates.

5. The committee urgently requests data on legume and grass species from our colleagues in other states to refine the hay grades and the technique for ration formulation. The following data are needed: acid-detergent fiber, neutral-detergent fiber, *in vivo* digestible dry matter, and dry matter intake per unit metabolic weight on legumes, grasses, and mixtures commonly fed to livestock and at several stages of maturity. *In vitro* data cannot be used because the data are difficult to interpret. Infromation is needed on silages as well as hays. If samples are available where *in vivo* digestible dry matter and dry matter intake is known but where acid-detergent fiber and neutral-detergent fiber analyses are not available, make this known to Dr. Dwayne A. Rohweder, Extension Agrono-

mist, 153 Moore Hall, Agronomy Department, University of Wisconsin, Madison, WI 53706. We will attempt to analyze the samples and complete the data.

6. Forage samples with known acid-detergent fiber, neutral-detergent fiber, *in vivo* digestible dry matter, and dry matter intake analyses are urgently requested. These samples will be used to perfect the infrared reflectance technique portion of this project. Notify Dr. Robert F. Barnes; National Program Staff; Plant and Entomological Sciences; ARS-USDA; Beltsville, MD 20705.

7. The committee urgently requests that in future research digestible energy intake data be collected on forages being used in feeding studies with livestock and furnished to the authors. These research data will be coupled with experience on a continuing basis to perfect present standards.

8. In April 1975, the Subcommittee co-sponsored a Hay Quality and Analysis Roundtable at Beltsville, Maryland, which set the stage for the development of two important programs. At the same meeting the use of infrared reflectance for estimating chemical composition of forage samples was first reported. The information present has been subsequently published. The potential for such instrumentation continues to be promising.

The merits of revising the Federal hay grades were considered, and a decision was made to pursue the establishment of new hay standards based upon chemical composition as related to animal response data. The present Federal hay grades were authorized by the Agricultural Marketing Act of 1946 and were last revised in the Handbook of Official Hay and Straw Standards in 1949. At present, the functions associated with the inspection and standardization of grain and hay have been transferred from the Agricultural Marketing Service to the Federal Grain Inspection Service (FGIS). The FGIS was established by PL94-582 as of November 1976. Today there are only a half dozen qualified hay inspectors in the United States. A new approach appears appropriate at this time.

LITERATURE CITED

Barnes, R. F. 1973. Laboratory methods of evaluating feeding value of herbage. Chap. 32. *In* Butler, G. W. and R. W. Bailey. Chemistry and Biochemistry of Herbage, Vol. No. 3, p. 179. Academic Press, New York.

Barnes, R. F. 1975. Predicting digestible energy values of hays. Proceedings of Laboratory Methods and Services Workshop. May 20–22, 1975. Salem, OR. Cosponsored by the Association of American Feed Control Officials, Inc.–Assoc. Official Anal. Chem. (AAFCA-AOAC).

Barnes, R. F., D. A. Rohweder and N. Jorgensen. 1977. The proposed establishment of hay standards. Presented at the 34th Southern Pasture and Forage Crop Improvement Conference, Auburn, AL; April 12–14, 1977.

Crampton, E. W., E. Donefer and L. E. Lloyd. 1960. A nutritive value index for forages. Proc. 8th Int. Grassl. Congr. p. 462. Reading, England.

Goering, H. K. and P. J. Van Soest. 1970. Forage fiber analysis (apparatus, reagents, procedures, and some applications). Agric. Handbook No. 379, US Department of Agriculture, Agricultural Research Service.

Jones, D. I. H. and R. W. Bailey. 1974. Hydrolysis of cell-wall carbohydrates of grasses by carbohydrases in relation to voluntary intake by sheep. J. Agr. Sci., Camb. 83:105.

Jones, D. V. H. and R. J. K. Walters. 1978. Structural constituents of grasses in relation to digestibility and voluntary intake. Abstr. J. Sci. Food Agr. (In press).

Jorgensen, N. 1971. Analysis of feedstuffs. Univ. of Wisconsin Dairy Science mimeo.

Krueger, C. R. 1967. Dry matter production, chemical composition, and nutritive value of some perennial forage grasses grown at five nitrogen levels and with alfalfa. Ph.D. Thesis, Univ. of Wisconsin-Madison.

Lee, Chin-tian and Dale Smith. 1972. Changes in the concentration of nitrogenous fractions in alfalfa herbage with advance in maturity. Agron. J. 64: 326.

Lema, Mejia F. 1972. *In vivo* and *In vitro* measures as predictors of the nutritive value of alfalfa and bromegrass hays. Ph.D. Thesis. Univ. of Wisconsin-Madison.

Lowery, R. S., G. W. Burton, J. C. Johnson, Jr., W. H. Marchant and W. C. McCormick. 1968. *In vivo* studies with Coast Cross I and other bermudas. Res. Bull. 55. College of Agriculture Experiment Stations. Univ. of Georgia.

Marten, G. C. 1970. Temperature as a determinant of quality of alfalfa harvested by bloom stage or age criteria. Proc. 11th Int. Grassl. Congr. p. 506. Surfurs Paradise; Queensland, Australia.

Marten, G. C., R. D. Goodrich, A. R. Schmid, J. C. Meiske, R. M. Jordan and J. C. Linn. 1975. Evaluation of laboratory methods for determining quality of corn and sorghum silages: II. Chemical methods for predicting *In vivo* digestibility. Agron. J. 67: 247.

Moore, J. E., O. C. Ruelke, C. E. Rios and D. E. Franke. 1970. Nutritive evaluation of "Pensacola" bahiagrass hays. Vol. 30:211. Proc. Soil and Crop Society of Florida.

Moore, J. E. and G. O. Mott. 1973. Structural inhibitors of quality in tropical grasses. p. 53. CSSA Spec. Publ. No. 4. Antiquality Components of Forages. Madison, WI.

Moore, J. E. 1975. Private Communication, University of Florida – Alfalfa and "Suwannee" bermudagrass from de La Torre *et al.* (In press).

Moore, J. E., E. J. Golding, III and R. F. Barnes. 1975. (Revised April, 1975). Assessment of applicability of present methods of predicting digestible energy values of hays. Prepared for AFGC Research Committee and Hay Marketing Task Force.

Norris, K. H., R. F. Barnes, J. E. Moore and J. S. Shenk. 1976. Predicting forage quality of infrared reflectance spectroscopy, J. Anim. Sci. 43: 889.

Osbourne, D. F., S. B. Cammell, R. A. Terry and G. E. Outen. 1970. The effect of chemical composition and physical characteristics of forages on their voluntary intake by sheep. p. 67. Ann. Rep. Grassland Research Institute.

Rohweder, D. A., R. F. Barnes, and N. Jorgensen. 1976a. The use of chemical analyses to establish hay market standards. Paper presented at the First International Symposium on Feed Consumption, Animal Nutrient Requirements, and Computerization of Diets. July 11–16, 1976. Logan, UT.

Rohweder, D. A., R. F. Barnes, and N. Jorgensen. 1976b. A standardized approach to establish market value for hay. Agron. Abstr. p. 112.

Rohweder, D. A., N. Jorgensen, and R. F. Barnes. 1976c. Using chemical analyses to provide guidelines in evaluating forages and establishing hay standards. Feedstufts 48(47):22. (November 15).

Shenk, J. S., W. N. Mason, M. L. Risius, K. H. Norris and R. F. Barnes. 1976. Application of infrared reflectance analysis to feedstuff evaluation. Proc. First Int. Sym. on Feed Comp., Logan, UT.

Smith, Dale. 1969. Influence of temperature on the yield and chemical composition of Vernal alfalfa at first flower. Agron. J. 61:470.

Smith, Dale. 1970. Influence of cool and warm temperatures and temperature reversal at inflorescence emergence on yield and chemical composition of timothy and bromegrass at anthesis. Proc. 11th. Int. Grassl. Congr., p. 510. Surfers Paradise; Queensland, Australia.

Smith, Dale. 1973. Distribution of dry matter and chemical constituents among plant parts of six temperate-origin forage grasses at early anthesis. R 2552. Res. Div. College of Agricultural and Life Sciences. Univ. of Wisconsin-Madison.

Smith, Dale. 1975. Influence of temperature on growth of Froker oats for forage. II. Concentrations and yields of chemical constituents. Can. J. Plant Sci. 55:897.

Tilley, J. M. A. and R. A. Terry. 1963. A two-stage technique for *In vitro* digestion of forage crops. J. Brit. Grassl. Soc. 18:104.

Ventura, M., J. C. Moore, D. C. Ruelke, and D. E. Franke. 1975. Effect of maturity and protein supplementation on voluntary intake and nutrient digestibility of 'Pangola' digitgrass hay. J. Anim. Sci. 40:769.

Vough, L. R. and G. C. Marten. 1971. Influence of soil moisture and ambient temperature on yield and quality of alfalfa forage. Agron. J. 63:40.

Walters, R. J. K. 1971. Variation in the relationship between *In vitro* digestibility and voluntary dry matter intake of different grass varieties. J. Agr. Sci., Camb. 76:243.