Chemical Composition and Digestibility of Tropical Grasses[1,2]

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ABSTRACT

One hundred and one tropical grasses, lightly fertilized with ammonium nitrate at the rate of 350 kg/ha, were harvested by hand (machete) at 30 days of growth. Crude protein content ranged from 9.8 to 23.8% while lignin content ranged from 2.6 to 7.9%. Wide ranges in the percentage of neutral-detergent fiber (45.7 to 79.2%), acid-detergent fiber (30.9 to 45.3%), hemicellulose (11.7 to 37.5%), and silica (0.4 to 5.5%) were obtained.

Digestibility estimates obtained by the Tilley and Terry method and neutral-detergent fiber digestibilities had wide ranges: 42.6 to 66.0% and 22.0 to 62.0%, respectively. Total dry matter disappearance ranged from 44.3 to 78.2%. Digestibility estimates from predictive equations ranged from 74.0 to 94.5% for estimated digestible dry matter, 67.3 to 91.7% for estimated true digestible dry matter, and 54.4 to 78.8% for estimated apparent digestible dry matter.

Analysis of variance showed significant variations between and within genera, indicating a possibility of genetic improvement through selection for high nutritive value.

Silica was variably correlated with digestibility depending on genera. Acid-detergent fiber seemed more important than lignin in determining digestibility values. The significance of the term L/ADF in relation to digestibility estimates among all data and among genera was much less for in vitro estimates than for estimates calculated from predictive equations. This may indicate that lignification of cellulose has less influence on digestibility of tropical than of temperate forages. The estimated digestibility values based on fibrous constituents were poorly

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correlated to in vitro digestibility values, indicating inadequacy of using predictive equations developed for temperate forages with tropical grasses. Correlation coefficients between measured parameters showed great variation among four genera: *Paspalum*, *Pennisetum*, *Digitaria*, and *Panicum*.

INTRODUCTION

The chemical composition and digestibility of forages are important criteria in deciding which forages should be planted and fed to ruminant animal. Newer analytical and artificial rumen procedures (4, 19, 20, 21, 22, 23) may offer an improved means of separating forage constituents into available and unavailable fractions. Information concerning nutritive value of tropical forage grasses, employing Goering and Van Soest's techniques (10), is rather limited even though values from these techniques have been used routinely to predict animal digestibility of temperate region forages.

Some data indicate that the crude fiber fraction is more digestible than the nitrogen-free extract (5). This demonstrates failure to separate the carbohydrates into soluble and insoluble, or digestible and indigestible, fractions and is the main criticism against the use of the proximate analysis scheme. Proximate analysis and total digestible nutrient system tend to overestimate the nutritive value of tropical grasses.

Further evidence shows that high environmental temperatures and rapid growth rates induce higher concentrations of lignin (L), total plant cell walls or neutral-detergent fiber (NDF), hemicellulose (H) and very low concentrations of soluble carbohydrates in tropical grasses (8,9).

The purpose of this study was to apply the newer techniques of forage evaluation developed by Goering and Van Soest (10) to tropical grasses, to use the chemical composition and estimated digestibility data to identify promising grass species for further detailed studies, and to identify important correlations, especially those between chemical components and estimated digestibility values.

PROCEDURE

Grass plots from the grass collection established at the College of Agricultural Sciences, University of Puerto Rico, Mayagüez, P.R., were treated with ammonium nitrate at the rate of 350 kg/ha. The plots were mowed in mid-July 1970 at an approximate height of 10 cm above soil level. One hundred and one grass samples were harvested by hand (machete) from selected plots after 30 days of growth on August 20, 1970, leaving a stubble height of 10 cm. They were chopped and mixed thoroughly, weighed at the field and oven-dried at 60°C for 3 days to determine field dry matter (FDM). Samples were ground in a Wiley[4] mill through a 1-mm screen. Prior to chemical analysis, the samples were reground through a 1-mm screen in a Wiley mill and stored in 16-oz air-tight polyethylene bags.

Crude protein (CP) as Kjeldahl nitrogen × 6.25 was determined by standard procedures (3). The primary fractions of NDF: acid-detergent fiber (ADF), lignin (L), cellulose (C), insoluble ash (A) and silica (Si) contents were determined according to the schemes of Goering and Van Soest (10). Hemicellulose was calculated as NDF minus ADF; and C, as loss in weight when ashed after the permanganate L determination. Ash was calculated as residue after incineration for C determination. The following three calculations from Van Soest's summative equation (10,22) were used as measures of digestibility:

/1/ percent estimated digestible dry matter (EDDM)

$$= 0.98\ (100 - \%\ \text{NDF}) + \%\ \text{NDF}\ [1.81 - 0.97\ \log_{10}(\%\ \text{L}/\%\ \text{ADF})\ 100],$$

/2/ percent estimated true digestible dry matter (ETDDM)

$$= 0.98\ (100 - \%\ \text{NDF}) + \%\ \text{NDF}\ [1.81 - 0.97\ \log_{10}(\%\ \text{L}/\%\ \text{ADF})\ 100] - 3.0\ (\%\ \text{Si}),$$

/3/ percent estimated apparent digestible dry matter (EADDM)

$$= 0.98\ (100 - \%\ \text{NDF}) + \%\ \text{NDF}\ [1.81 - 0.97\ \log_{10}(\%\ \text{L}/\%\ \text{ADF})\ 100] - 3.0\ (\%\ \text{Si}) - 12.9$$

A two-stage Tilley and Terry (TT) procedure (19) for estimating in vitro digestibility was performed on all samples using a phosphate buffer in place of their bicarbonate buffer. Digestibility (11) was estimated using the regression equation: $Y = 13.81 + .77X$, where Y equals percent digestibility and X equals percent DM disappearance. This equation, similar to that of others (13), was developed for alfalfa. A similar sample was also fermented and NDF determined on the residue. Percent digestible cell walls or neutral-detergent fiber (DNDF) was calculated as (100% − % NDF in residue after fermentation) × 100 ÷ % NDF in sample before fermentation. Percent total dry matter disappearance (TDMD) was calculated as (100% − % DM in residue after fermentation) × 100 ÷ % DM in sample.

The data were subjected to variance and to simple correlation analyses (18).

[4] Trade names are used in this paper solely for the purpose of providing information. Mention of a trade name does not constitute a guarantee or warranty of the equipment by the Agricultural Experiment Station of the University of Puerto Rico or an endorsement over other equipment or materials not mentioned.

RESULTS AND DISCUSSION

CHEMICAL CONSTITUENTS

These 101 tropical grass species ranged from 9.8 to 23.8% CP (table 1). The CP content was lowest in *Vetiveria* and *Cenchrus*. Four genera averaged over 17% CP. The relatively high CP values observed in this study are probably due to the age of the forages. Similar values were obtained by Coward-Lord et al. (7) for tropical grasses in Puerto Rico. Ten of these 101 samples were harvested every 30 days until 180 days of age (2,6,7). CP was higher at the younger ages but decreased as forage grasses advanced in maturity.

The relatively low values for L (2.6 to 7.9%) were also a reflection of the young age at which the forages were harvested. These values compared well with data reported by Ademosum et al. (1), where age or stage of maturity was not mentioned for the samples, and to those of Coward-Lord et al. (6) and Olubajo et al. (14). The relatively wide ranges of A and Si may be due to generic variations and plant age (6,14,23).

The NDF ranged from 45.7 to 79.2% (table 1). These values were similar to those obtained by Coward-Lord et al. (6) for 10 genera at 30 days of age. Five genera had values as low in NDF (<60%) as many temperate grasses (11,15,22), indicating that not all tropical grasses contain more fibrous material than temperate grasses. However, the majority of these tropical grasses, even at 30 days of growth, had a high NDF content. The ranges of 30.9 to 45.3% for ADF, 11.7 to 37.5% for H, and 24.3 to 38.5% for C compared favorably with those reported for Nigerian grasses (1). Coward-Lord et al. (6) found a range of 32.8 to 45.2% ADF for 10 of these genera at the 30-day-growth stage which is very similar to that found in this study (table 1).

Vetiveria species had the lowest mean values for CP (10.2%) but the highest for NDF (76.9%), ADF (44.4%), C (36.4%), and L (6.4%) (table 1). *Leersia* had highest mean values for CP (23.8%), A (5.6%), and Si (5.5%) but lowest for C (25.0%) and L (3.3%). Lowest mean values were obtained for FDM, NDF, ADF, H, A, and Si contents in *Setaria* (12.5%), *Thichadne* (56.2%), *Axonopus* (32.2%), *Thichadne* (22.2%), *Hemarthria* (1.0%), and *Hemarthria* (0.6%), respectively. Highest mean values for FDM and H contents were obtained in *Leptocoryphium* and *Sorghastrum* (28.4%), and *Chloris* (34.5%), respectively.

Significant differences between genera (table 2) were obtained in CP content, with *Pennisetum* being significantly ($P < .05$) greater than all other genera. *Cenchrus* was significantly ($P < .05$) greater in NDF than *Pennisetum*, *Brachiaria*, and *Digitaria;* in ADF than *Panicum*, *Pennisetum*, and *Brachiaria;* and in C than *Panicum*, *Paspalum*, *Pennisetum*, and *Brachiaria*. *Paspalum* was significantly ($P < .05$) greater

TABLE 1.—*Chemical composition (%) and estimated digestibility (%) of 28 genera of tropical grasses harvested at 30 days of age*

Genera	n[1]	FDM	CP	NDF	ADF	H	C	L	A	Si	TDMD	DNDF	TT	EDDM	ETDDM	EADDM
Andropogon	2	20.5	12.9	73.5	42.0	31.5	33.6	5.0	3.4	2.9	53.0	35.9	55.5	82.4	73.7	60.8
Axonopus	1	17.8	15.9	58.2	32.2	26.0	26.6	3.5	2.1	2.0	75.4	57.7	65.0	88.1	82.0	69.1
Arundinela	1	25.1	12.4	72.8	39.3	33.5	31.2	4.3	3.8	3.2	57.3	42.1	56.1	84.8	75.2	62.3
Arundo	1	19.4	16.6	62.6	39.0	23.9	31.2	4.1	3.2	2.9	68.6	49.8	57.9	87.9	79.3	66.4
Brachiaria	5	17.1	14.6	61.5	33.6	28.0	28.8	3.7	1.6	1.2	73.0	55.9	64.1	86.8	83.3	70.4
Cenchrus	5	18.1	10.9	70.1	43.0	27.1	36.3	4.8	1.9	1.6	54.1	34.5	46.5	85.2	80.5	67.6
Chloris	1	17.0	13.5	73.1	38.5	34.5	30.0	5.5	2.6	2.4	72.2	62.0	64.0	76.6	69.5	56.6
Cymbopogon	2	22.7	12.2	59.6	33.6	26.0	26.2	5.2	2.5	2.1	59.4	31.9	57.8	79.0	72.6	59.7
Cynodon	3	24.6	14.7	70.9	39.1	31.8	32.3	4.8	1.9	1.6	59.1	42.8	59.8	81.7	76.9	64.0
Dicanthium	1	17.9	14.2	65.8	39.7	26.1	33.0	5.0	1.7	1.5	66.8	49.5	56.8	82.2	77.5	64.6
Digitaria	7	16.8	13.5	64.7	40.2	24.4	33.9	4.7	1.7	1.3	70.0	53.8	62.2	84.8	80.9	68.0
Eragrostis	1	19.2	12.6	67.8	41.4	26.4	34.8	5.3	1.5	1.4	53.9	32.0	53.5	81.6	77.5	64.6
Eriochloa	2	15.7	18.8	58.1	33.2	24.9	27.9	4.3	1.6	1.3	71.0	50.0	59.1	83.5	79.6	66.8
Hemarthria	1	24.3	12.3	68.2	38.4	29.8	31.3	6.2	1.0	.6	62.0	44.3	65.9	74.7	73.0	60.1
Hyparrhenia	1	20.9	16.0	63.5	38.3	25.1	31.4	3.7	3.2	2.8	72.5	56.6	55.6	90.0	81.7	68.8
Leersia	1	27.1	23.8	60.6	33.4	27.1	25.0	3.3	5.6	5.5	69.3	49.3	62.7	89.9	73.4	60.5
Leptocoryphium	1	28.4	12.8	71.5	43.0	28.4	35.0	6.1	2.5	2.2	44.3	22.0	46.3	77.1	70.5	57.6
Panicum	20	16.8	14.2	66.5	39.0	27.6	32.4	4.8	1.7	1.4	68.0	52.2	60.8	82.9	78.6	65.7
Paspalum	12	18.8	13.5	66.3	41.0	25.2	33.0	5.6	2.3	1.6	61.6	41.6	53.4	80.2	75.5	62.6
Pennisetum	22	14.5	17.2	62.5	36.7	25.7	30.7	3.8	2.2	1.8	65.7	45.2	53.5	89.2	83.8	70.9
Setaria	1	12.5	15.1	64.0	35.6	28.4	30.4	4.7	1.1	1.0	72.3	56.8	48.4	75.7	72.6	59.7
Sporobolus	2	23.0	16.7	71.3	37.2	34.1	31.2	4.7	1.3	1.1	68.9	56.3	60.5	81.5	78.2	65.3
Sorghastrum	2	28.4	12.1	71.2	42.1	29.1	32.7	6.0	2.3	2.1	59.7	43.3	51.8	77.3	71.1	58.2
Sorghum	1	16.0	15.2	58.5	34.9	23.6	29.0	4.6	1.4	1.0	70.6	49.7	64.4	82.9	80.0	67.1
Themeda	1	19.7	11.2	72.4	42.0	30.4	35.0	4.3	2.9	2.6	54.2	36.7	56.6	87.3	79.4	66.5
Thichachne	1	15.0	19.1	56.2	34.0	22.2	28.5	4.0	1.4	1.3	78.2	61.1	58.7	86.0	82.1	69.2
Tripsacum	2	17.7	15.3	68.5	37.8	30.7	30.7	4.4	2.4	2.0	65.6	50.0	57.5	83.7	77.6	64.7
Vetiveria	1	19.2	10.2	76.9	44.4	32.5	36.4	6.4	1.6	1.2	51.9	37.4	49.3	75.2	71.6	58.7
Average		17.9	14.7	65.5	38.5	27.1	31.8	4.7	2.0	1.7	65.1	46.9	56.9	83.8	78.8	65.9
Range-Minimum		9.1	9.8	45.7	30.9	11.7	24.3	2.6	.7	.4	44.3	22.0	42.6	74.0	67.3	54.4
Maximum		30.6	23.8	79.2	45.3	37.5	38.5	7.9	6.5	5.5	78.2	62.0	66.0	94.5	91.7	78.8

[1] n, number of species and varieties per genus; FDM, dry matter at harvest; CP, crude protein—N × 6.25; NDF, neutral-detergent fiber; ADF, acid-detergent fiber; H, hemicellulose; C, cellulose; L, lignin; A, ash; Si, silica; TDMD, total dry matter disappearance; DNDF, digestible neutral-detergent fiber; TT, digestible dry matter from Tilley and Terry determination; EDDM, estimated digestible dry matter; ETDDM, estimated true digestible dry matter; EADDM, estimated apparent digestible dry matter.

TABLE 2.—*Chemical composition (%) and estimated digestibility (%) (mean, minimum and maximum) for six specific genera*

Constituent[1]	Panicum (n = 20)			Paspalum (n = 12)			Pennisetum (n = 22)			Brachiaria (n = 5)			Cenchrus (n = 5)			Digitaria (n = 7)		
	Mean[2]	Minimum	Maximum	Mean	Minimum	Maximum	Mean	Minimum	Maximum	Mean	Minimum	Maximum	Mean	Minimum	Maximum	Mean	Minimum	Maximum
FDM	16.8 a	13.8	21.4	18.9 a	15.0	25.8	14.5 bc	9.1	20.8	17.1 ac	14.0	19.4	18.1 a	15.3	21.9	16.8 ac	14.6	19.0
CP	14.2 a	9.8	18.4	13.5 a	11.2	16.1	17.2 b	12.6	22.5	14.6 a	12.4	18.1	10.9 cd	9.8	12.3	13.6 ad	10.1	17.4
NDF	66.5 ae	59.0	74.7	66.3 abe	61.6	71.3	62.5 c	45.7	72.0	61.5 cd	58.4	64.8	70.1 e	68.0	72.5	64.7 ac	60.4	68.5
ADF	39.0 a	34.9	43.7	41.0 ae	36.3	45.3	36.6 b	30.9	42.2	33.6 c	31.6	36.6	42.9 def	42.1	44.0	40.2 af	36.5	42.2
H	27.6 a	24.1	32.1	25.2 a	18.7	28.5	25.8 a	11.7	37.3	28.0 a	26.8	29.1	27.2 a	25.5	30.0	24.4 a	20.4	26.7
C	32.4 ac	28.5	36.1	33.0 a	29.7	38.5	30.5 be	27.1	35.8	28.8 ce	26.5	31.3	36.3 df	35.2	37.3	33.9 af	32.3	36.7
L	4.8 a	3.9	7.0	5.6 be	4.3	7.9	4.0 cf	2.6	5.4	3.7 dfg	3.1	4.0	4.6 aeg	4.2	4.9	4.7 ag	3.4	5.7
A	1.7 a	1.0	2.5	2.3 a	1.2	6.5	2.1 a	1.1	3.4	1.6 a	1.0	2.1	1.7 a	1.1	2.9	1.7 a	.7	2.2
Si	1.4 a	.7	2.3	1.6 ac	.9	2.5	1.8 bc	.8	3.3	1.2 a	.8	1.7	1.4 ac	.8	2.4	1.3 a	.4	1.6
H/C	.9 a	.7	1.0	.8 ab	.5	.9	.9 a	.4	1.3	1.0 c	.9	1.1	.8 a	.7	.8	.7 b	.6	.8
L/ADF	.1 ac	.1	.2	.1 a	.1	.2	.1 b	.1	.2	.1 bc	.1	.1	.1 bc	.1	.1	.1 bc	.1	.1
L/C	.2 ac	.1	.2	.2 b	.1	.3	.1 c	.1	.2	.1 c	.1	.1	.1 c	.1	.1	.1 c	.1	.2
L/H	.2 acd	.1	.3	.2 b	.2	.4	.2 acd	.1	.3	.1 ac	.1	.1	.2 ab	.1	.2	.2 ac	.1	.2
TDMD	68.0 af	50.5	74.3	61.6 b	56.7	66.5	65.7 ad	46.5	75.7	73.0 ef	71.0	76.1	54.1 c	52.1	57.2	70.0 aef	63.6	73.9
DNDF	52.2 a	26.1	60.8	41.6 bf	34.4	48.9	44.9 b	24.1	61.6	55.9 ae	51.9	59.0	34.5 cf	30.1	40.5	53.6 ad	42.7	56.7
TT	60.8 a	53.7	65.1	53.4 b	48.2	63.1	53.5 b	42.6	63.8	64.1 d	61.6	66.0	46.7 c	42.9	52.2	62.1 d	59.2	64.7
EDDM	82.9	74.1	88.0	80.2	74.0	87.9	87.4	79.7	94.5	86.8	84.6	92.7	86.2	84.2	87.8	84.8	79.4	91.4
EADDM	65.7	54.4	71.1	62.6	55.0	71.7	69.1	56.9	78.8	70.4	67.6	74.9	68.9	66.1	71.5	68.0	61.6	77.2

[1] FDM, dry matter at harvest; CP, crude protein; NDF, neutral-detergent fiber; ADF, acid-detergent fiber; H, hemicellulose; C, cellulose; L, lignin; A, ash; Si, silica; TDMD, total dry matter disappearance; DNDF, digestible neutral-detergent fiber; TT, digestible dry matter from Tilley and Terry determination; EDDM, estimated digestible dry matter; EADDM, estimated apparent digestible dry matter.

[2] Mean values with one or more common letter(s) are not significant at the 5% level.

in L than *Panicum*, *Pennisetum*, *Brachiaria*, and *Digitaria*. *Pennisetum* was significantly ($P < .05$) greater in Si than *Panicum*, *Brachiaria*, and *Digitaria*. However, no significance was found among genera in H or A contents.

ESTIMATES OF DIGESTIBILITY

Values for estimated digestibility (table 1) ranged from 44.3 to 78.2% for TDM, 22.0 to 62.0% for DNDF, and 42.6 to 66.0% for TT values. The seven genera with very low DNDF values of 22.0 to 37.4% deserve particular attention. Equations exist for predicting digestibility with Si and L as the main predictors (1,20,21,22,24). For Puerto Rican grasses, Arroyo-Aguilú and Coward-Lord (2) developed an equation for estimating digestibility from chemical composition: CP, C, L, and Si. Data in table 1 show that the genera with the lowest DNDF values were not necessarily high in Si and L although most were near average or slightly above. At least two forms of Si are known to occur in forages: insoluble and soluble (16,17,24,25). Initial studies indicated that a soluble fraction may be more closely associated with reduction of digestibility of the cellulosic carbohydrate than the insoluble form (25). Soluble Si can influence in vitro rumen fermentation and growth and reproduction in rats (16,17). However, the proportion of soluble to insoluble Si was not determined in this study.

Low level digestible organic matter has also been attributed to an unusually high A content of approximately 20% (15). Total A content of the grasses was not determined in this study, but insoluble A amounted to only 2%.

These data suggested that some uncharacterized components in addition to Si and L exert a strong influence on DNDF and TDMD. In general, the species that showed the least DNDF are those not usually grazed by cattle. A component in these forages that is inhibitory or toxic to rumen microbes appears possible and such compounds are known to occur in grasses (4). However, preliminary evidence indicated little inhibitory effect when water extracts of several of these forages of low digestibility were added to a standard alfalfa sample in the TT procedure. Further investigations using other extraction procedures or fiber preparations appear desirable.

Among the six genera (table 2), *Brachiaria* had highest digestibility coefficients for TDMD and DNF, and *Cenchrus* was lowest in TDMD, DNDF, and TT values. Significant ($P < 0.1$) differences in TDMD and DNDF were obtained between genera, with *Brachiaria* being significantly ($P < .01$) greater than *Paspalum*, *Pennisetum*, and *Cenchrus*. Similar significant ($P < .01$) differences in genera were obtained in TT digestibilities.

VARIATIONS AMONG AND WITHIN GENERA

A summary of the analyses of variance for chemical components, their ratios, and digestibility values is given in table 3. For the 101 samples, L/H ratio was the only variable not statistically significant. All other variables were significant (P < .01) with L/C ratio and H content being significant at P < .05. This demonstrated that differences in chemical composition and estimated digestibility do exist among grasses grown under the same environmental and agronomic conditions. It also suggests that there may be a possibility of genetic improvement for tropical grasses.

TABLE 3.—*Summary of analyses of variance for chemical constituents, their ratios and estimated digestibilities for the 101 tropical forages*

Constituent	Mean square	F ratio
Chemical components		
Field dry matter	41.96	4.28**[1]
Crude protein	17.97	3.35**
Neutral-detergent fiber	56.64	3.09**
Acid-detergent fiber	27.51	4.04**
Hemicellulose	21.79	1.87*[2]
Cellulose	18.01	3.62**
Lignin	1.88	2.84**
Ash	1.28	2.14**
Silica	1.22	4.32**
In vitro digestibility coefficients		
True dry matter disappearance	129.45	4.07**
Digestible neutral-detergent fiber	196.91	3.58**
Digestible dry matter from Tilley and Terry	16.37	5.31**
Ratios of the chemical components		
Lignin/Acid-detergent fiber	7.81	2.30**
Lignin/Hemicellulose	.003	1.51
Lignin/Cellulose	.001	1.90**
Hemicellulose/cellulose	3.22	2.73**

[1]** Significant at the 1% level. [2]** Significant at the 5% level.

An analysis of variance in three genera: *Paspalum*, *Panicum*, and *Pennisetum*, with 12 or more species each, showed little variation in *Paspalum* but significant (P < .01) variation among CP, ADF, and C in *Panicum* and *Pennisetum*. These suggested a good possibility for genetic selection in nutritive value among *Panicum* and *Pennisetum*.

Correlation coefficients for the 101 samples are summarized in table 4. FDM was positively correlated with the fibrous constituents and negatively correlated with CP and estimates of digestibility. The CP content was significantly (P < .01) correlated with other indicators of quality: negatively with fibrous constituents except Si and positively with in vitro digestibility values (for TT, $P < .05$). There was a significant positive correlation between ADF and L/C ($P < .01$), L/ADF ($P < .05$), or L/H ($P < .01$), but H/C was negatively related to ADF (−.46, $P < .01$)'

The fibrous constituents (NDF, ADF) of the grasses (table 4) were significantly ($P < .05$) but negatively correlated to the estimated digestibility values. NDF was significantly ($P < .01$) correlated to ADF, H, C, and L. C was significantly ($P < .01$) correlated to L, which is in agreement with most available data (6,16). Si content, which is important in determining the digestibility coefficients of most temperate grasses (5,24) was not significantly correlated to TDMD, DNDF or TT values. Ash was significantly related to Si (.82, $P < .01$) but neither was significantly related to digestibility values except for ETDDM. The component with the greatest negative influence on the digestibility of tropical grasses was ADF. The effect of C and L was also negative and similar to the data of Arroyo-Aguilú and Coward-Lord (2). Estimated digestibility by TT was related to CP ($P < .05$), NDF ($P < .05$), ADF ($P < .01$), and C ($P < .01$) but not to FDM, H, L, or Si. In Van Soest's summative equation, the L/ADF ratio is the most important item in estimating the DNDF of temperate forages (10,22). In this study, L/H, and not L/ADF, was significantly ($P < .05$) correlated to DNDF and emphasized interspecies variation rather than maturity as a large factor in L-fiber relationships. None of the ratios of chemical constituents were highly related to TDMD, DNDF or TT estimates. There were relatively large differences in relationships of constituents to TDMD and DNDF; however, correlations between these two variables were significant ($P < .01$). Estimated digestibility by TT was significantly ($P < .01$) correlated with both TDMD and DNDF but not with estimates from the summative equation (ETDDM). The ETDDM was significantly ($P < .01$) correlated with TDMD but not with DNDF.

Intrageneric correlations for four genera are presented in tables 5, 6. These correlations show many dissimilarities among parameters measured for the different genera, and only a portion of these will be specifically mentioned. The CP was usually negatively related to the fibrous constituents (NDF, ADF, H, C, L) in each genera except for L and/or H in the *Paspalum* genera. Among the fibrous constituents, correlations varied among genera, being consistently positive only for *Panicum*. Fibrous constituents and CP had variable relationships to digestibility values. Correlations between CP and digestibilities were all positive only in *Pennisetum* and *Panicum*. Digestibility correlations with NDF and ADF were all negative in *Pennisetum* and *Panicum*. Correlations between L and digestibilities were negative and/or low in all four species. Fibrous constituents were variably related to TDMD. In *Penni-*

TABLE 4.—*Selected simple correlation coefficients among chemical components, their ratios and in vitro and estimated digestibility values for 101 samples*

Constituent[1]	CP[1]	NDF	ADF	H	C	L	Si	L/ADF	L/C	L/H	TDMD	DNDF	TT	ETDDM
FDM	-0.40**[2]	0.45**	0.32**	0.34**	0.19	0.36**	0.23*[3]	0.26**	0.30**	0.08	-0.47**	-0.36**	-0.10	-0.42**
CP		-.63**	-.68**	-.26**	-.69**	-.48**	.17	-.24*	-.21*	-.19	.46**	.27**	.20*	.27**
NDF			.71**	.76**	.68**	.45**	-.02	.16	.15	-.09	-.56**	-.21*	-.22*	-.36**
ADF				.08	.90**	.65**	.03	.23*	.26**	.47**	-.57**	-.36**	-.38**	-.38**
H					.12	.04	-.06	.01	-.03	-.57**	-.27**	.02	.03	-.15
C						.38**	-.21*	-.04	-.08	.21*	-.49**	-.28**	-.35**	-.05
L							.01	.87**	.89**	.77**	-.38**	-.26**	-.16	-.85**
Si								-.03	.11	.04	-.10	-.13	-.04	-.40**
L/ADF									.96**	.79**	-.15	-.11	.00	-.87**
L/C										.73**	-.18	-.16	-.01	-.89**
L/H											-.15	-.23*	-.16	-.57**
TDMD												.92**	.65**	.30**
DNDF													.66**	.19
TT														.06

[1] CP, crude protein; NDF, neutral-detergent fiber; ADF, acid-detergent fiber; H, hemicellulose; C, cellulose; L, lignin; Si, silica; TDMD, total dry matter disappearance; DNDF, digestible neutral-detergent fiber; TT, digestible dry matter from Tilley and Terry determination; ETDDM, estimated true digestible dry matter; FDM, dry matter at harvest.

[2] ** Significant at the 1% level.

[3] * Significant at the 5% level.

TABLE 5.—*Correlation coefficients between chemical constituents and in vitro and estimated digestibility values for two genera: Paspalum (n = 12) in lower left portion of table; Pennisetum (n = 22) in the upper portion of table*

Constituent[1]	FDM	CP	NDF	ADF	H	C	L	Si	L/ADF	L/C	L/H	TDMD	DNDF	TT	ETDDM
FDM		−0.70**[2]	0.54**	0.82**	0.08	0.75**	0.65**	0.06	0.38	0.35	0.26	−0.71**	−0.56**	−0.52*	−0.42*
CP	−0.41		−.65	−.85**	−.20	−.83**	−.58**	.02	−.26	−.20	−.10	.56**	.32	.36	.34
NDF	−.04	.03		.62**	.82**	.64**	.39	−.11	−.14	.10	−.39	−.59**	−.18	−.35	−.25
ADF	−.16	.04	.40		.06	.92**	.76**	.13	.42*	.38	.38	−.66**	−.46*	−.33	−.50*
H	.10	−.01	.64*[3]	−.45		.13	−.07	−.23	−.13	−.14	−.78**	−.27	.10	−.20	.05
C	−.28	−.45	.36	.59*	−.14		.50*	−.20	.10	.03	.18	−.68**	−.48*	−.44*	−.16
L	.20	.48	.29	.48	−.12	−.34		.48*	.90**	.88**	.60**	−.35	.21	.04	−.91**
Si	.42	.11	.12	−.12	.22	−.41	.29		.59**	.67**	.47*	.18	.16	.37	−.74**
L/ADF	.34	.49	.16	.12	.05	−.63*	.93**	.39		.99**	.58**	−.07	.00	.26	−.96**
L/C	.27	.54	.08	.24	−.12	−.61*	.95**	.38	.97**		.59**	−.04	−.02	.27	−.97**
L/H	.06	.41	−.15	.62*	−.67*	−.20	.81**	.08	.65*	.78**		.00	−.21	.20	−.55**
TDMD	−.46	−.29	−.23	−.37	.00	.04	−.57*	−.37	−.50	−.49	−.46		.90**	.70**	.13
DNDF	−.48	−.26	.33	−.18	.48	.23	−.43	−.21	−.42	−.46	−.57*	.82**		.66**	.02
TT	−.21	.12	−.02	−.59*	.47	−.22	−.36	−.06	−.17	−.27	−.53	.30	.28		−.23
ETDDM	−.39	−.42	−.35	−.10	−.25	.56	−.86**	−.61*	−.94**	−.89**	−.48	.54	.34	.10	

[1] FDM, dry matter at harvest; CP, crude protein; NDF, neutral-detergent fiber; ADF, acid-detergent fiber; H, hemicellulose; C, cellulose; L, lignin; Si, silica; TDMD, total dry matter disappearance; DNDF, digestible neutral-detergent fiber; TT, digestible dry matter from Tilley and Terry determination, ETDDM, estimated true digestible dry matter.

[2] Significant at the 1% level.

[3] Significant at the 5% level.

TABLE 6.—*Correlation coefficients between chemical constituents and in vitro and estimated digestibility values for two genera: Digitaria (n = 7) in lower left portion of table; Panicum (n = 20) in upper right portion of table*

Constituent[1]	FDM	CP	NDF	ADF	H	C	L	Si	ADF	L/C	L/H	TDMD	DNDF	TT	ETDDM
FDM		−0.07	0.17	−0.01	0.25	0.04	0.03	0.05	0.01	0.00	−0.05	−0.16	−0.14	0.04	−0.03
CP	0.21		−.74**[2]	−.69**	−.42	−.71**	−.36	−.05	−.89**	−.10	−.10	.33	.16	.59	.24
NDF	.10	−.77*		.70**	.76**	.79**	.12	−.04	−.21	−.19	−.23	−.28	−.04	−.22	−.01
ADF	−.11	−.93**	.78*		.07	.94**	.58**	.46*	.21	.25	.40	−.20	−.04	−.25	−.48*
H	.20	−.35	.80*	−.26		.24	.58**	−.46*	−.50*	−.50*	−.71**	−.30	−.12	−.09	.44*
C	−.32	−.88**	.80*	.79*[3]	.53		.36	.21	−.02	−.02	.16	−.09	.09	−.18	−.22
L	.28	−.41	.38	.61	−.03	.10		.48*	.92**	.92**	.92**	−.07	−.03	−.46*	−.97**
Si	−.04	−.60	.40	.80*	−.15	.30	.74*		.35	.42	.56**	−.02	−.03	.07	−.61**
L/ADF	.34	−.19	.20	.40	−.12	−.13	.97**	.63		.99**	.91**	.01	−.03	−.43*	−.93**
L/C	.36	−.17	.16	.39	−.18	−.18	.96**	.66	.99**		.92**	−.04	−.07	−.41	−.95**
L/H	.13	−.21	−.05	.42	−.52	−.15	.87**	.74	.88**	.90**		.06	.01	−.31	−.92**
TDMD	.17	−.01	−.29	.05	−.52	.03	−.14	.05	−.20	−.16	.14		.96**	.42	.04
DNDF	.20	−.37	.15	.41	−.18	.42	.01	.23	−.13	−.11	.11	.90**		.38	.03
TT	−.42	.46	−.38	−.30	−.32	−.27	−.42	.00	−.38	−.34	−.19	.08	−.10		.39
ETDDM	−.25	.40	−.37	−.61	.05	−.08	−.99**	−.79*	−.97**	−.96**	−.88**	.17	.02	.36	

[1] FDM, dry matter at harvest; CP, crude protein; NDF, neutral-detergent fiber; ADF, acid-detergent fiber; H, hemicellulose; C, cellulose; L, lignin; Si, silica; TDMD, total dry matter disappearance; DNDF, digestible neutral-detergent fiber; TT, digestible dry matter from Tilley and Terry determination; ETDDM, estimated true digestible dry matter.

[2] Significant at the 1% level.

[3] Significant at the 5% level.

setum, NDF, ADF, and C were significantly (P < .01) and negatively related to TDMD; whereas, only L was significantly (P < .05) related in *Paspalum;* and none were significantly (P < .05) related in *Digitaria* and *Panicum*.

FDM content was negatively related to all four digestibility values only in *Pennisetum* (P < .05) and *Paspalum*. The negative correlation between FDM and CP was significant (P < .01) in *Pennisetum*. However, the relationship between FDM and CP was positive in *Digitaria*. Variable relationships were obtained between FDM and the fibrous constituents among the four groups.

Significant negative correlations were obtained between L content and TDMD in *Paspalum* (P < .05); TT in *Panicum* (P < .05); and ETDDM in *Paspalum* (P < .01), *Pennisetum* (P < .01), *Digitaria* (P < 0.1), and *Panicum* (P < .01). L content was not significantly correlated with any of the four genera.

Si content was significantly related to ADF (P < .05) and L (P < .05) in *Digitaria* and *Panicum*. ETDDM was the only digestibility estimate related to Si: negative and significant in *Paspalum* (P < .05), *Pennisetum* (P < .01), *Digitaria* (P < .05), and *Panicum* (P < 0.1). Variable relations of Si to other constituents were observed. Van Soest et al. (26) obtained significant (P < .05) correlations between Si and in vitro true digestibility in *Panicum* (.41), *Brachiaria* (.41), and *Cynodon* (–.45).

All estimates of digestibility were negatively correlated to L/ADF, L/C, and L/H in *Paspalum* and *Digitaria*, with significant differences between ETDDM and L/ADF or L/C (P < .01) and between DNDF and L/H (P < .05) in *Paspalum;* between TT and L/ADF (P < .05) in *Pennisetum;* and between ETDDM and L/ADF, L/C, or L/H (P < .01) in *Digitaria*, *Panicum*, and *Pennisetum* (P < .01).

The estimated value (ETDDM) based on the summative equation was not always related to the digestibility values derived from in vitro fermentations (TDMD, DNDF, TT). The two values (TDMD, DNDF) derived from the same fermentations were always related (P < .01) in the four genera. The TT value was not consistently related to TDMD and DNDF or ETDDM. The correlation was positive and significant (P < .01) between TDMD and DNDF within *Pennisetum*.

The significance of the term L/ADF in relation to estimates of digestibility among overall data (table 4) and among genera (tables 5, 6) was much less for estimates based on fermentation techniques than for estimates calculated from NDF, ADF, and L analysis. This may indicate that lignification of C has less influence on digestibility of tropical forages than of temperate forages (21). The results of this study suggest that the significance of the L/ADF term as an indicator of tropical forage digestibility needs reevaluation. Pfander et al. (15) found similar discrepancies between digestibility estimates based on fermentation and Van Soest's summative equation using temperate forage and browse samples. Johnson et al. (12) indicated that tropical and temperate forages do not behave in the same manner. Clearly, more research relating in vivo digestibility to these newer analytical values is needed for tropical forages. Possibly equations applicable to temperate forages may not necessarily be appropriate for tropical forages.

RESUMEN

Ciento una muestras de yerbas tropicales de 30 días de edad se evaluaron con respecto a sus components químicos. Estas ya estaban establecidas en parcelas de 10 m.[2] en la collección de gramíneas del Colegio de Ciencias Agrícolas de la Universidad de Puerto Rico, localizada en Mayagüez. Las yerbas se abonaron ligeramente con nitrato amónico a razón de 350 kg./Ha.

El contenido de proteína cruda varió de 9.8 a 23.8% mientras que el de lignina varió de 2.6 a 7.9% Se obtuvieron variaciones amplias en contenidos de fibra neutrodetergente (45.7 a 79.2%), fibra ácidodetergente (30.9 a 45.3%), hemicelulosa (11.7 a 37.5%) y sílice (0.4 a 5.5%).

Los estimados de digestibilidad obtenidos por el método de Tilley y Terry y la digestibilidad de la fibra neutrodetergente presentaron variaciones amplias: 42.6 a 66.0 y 22.0 a 62.0%, respectivamente. El coeficiente de desaparición de la materia seca total varió de 44.3 a 78.2%. Los estimados de digestibilidad a base de ecuaciones de predieción variaron de 74.0 a 94.5% para la materia seca digestible estimada, de 67.3 a 91.7% para la materia seca real digestible estimada y de 54.4 a 78.8% para la materia seca parente digestible estimada.

El análisis de varianza presentó variaciones significativas entre y dentro de los géneros, indicando la posibilidad de mejoramiento genético por selección de ciertos géneros a base del alto valor nutritivo.

La correlación de la sílice con la digestibilidad varió entre los géneros. La fibra acidodetergente aparentemente es más importante que la lignina para determinar los valores de digestibilidad. La contribución de la razón lignina a fibra ácidodetergente al estimar la digestibilidad, incluyendo todos los datos, fue mucho menor para los estimados in vitro que para los estimados calculados de ecuaciones predictivas. Esto tiende a indicar que la lignificación de la celulosa tiene una menor influencia en la digestibilidad de los forrajes tropicales que en los de zonas templadas. Los coeficientes de digestibilidad basados en los componentes fibrosos no estuvieron bien correlacionados con los coeficientes de digestibilidad in vitro, lo cual indica que las ecuaciones de predicción desarrolladas para los forrajes de zonas templadas no son necesariamente las más adecuadas para los forrajes tropicales. Se observó una gran variación en los coeficientes de correlación obtenidos entre los correspondientes parámetros evaluados en cuatro géneros: *Paspalum*, *Pennisetum*, *Digitaria* y *Panicum*.

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