1-1-1979

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Bulletin 669T
June 1979

West Virginia University
Agricultural and Forestry Experiment Station

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Cover

Location of experimental plots at Kabanyolo, Uganda.

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Summary

The chemical composition of tropical forages (42 grasses and 11 legumes) was determined at regular intervals over a five-month growth period at Kabanyolo, Uganda. Cell-wall components (CWC), acid-detergent fiber (ADF) and acid-detergent lignin values increased in a linear fashion, and crude protein concentration declined curvilinearly, with advancing maturation of the forage. Significant family, genus and species effects on composition were noted. Concentrations of CWC, ADF and ADL were, however, generally comparable to those observed for temperate forages. Simple and multiple correlation and regression analyses were run to define relationships of composition with *in vitro* digestible dry matter (DDM). For all forages, digestibility was significantly correlated with the individual components CWC, ADF, lignin, crude protein, and hemicellulose. There were marked differences between grasses and legumes in regressions of lignin and CWC on *in vitro* digestibility. Within family, lignin or CWC appeared to be the best single predictor of digestibility.

In multiple regression analysis, the most significant component affecting DDM was ADF, accounting for 38 percent of the variability. A regression equation including CWC and lignin improved the proportion of variability accounted for from 38 to 74 percent in all forages. The general equation was: DDM (percent) = 109.5 - 0.53 CWC (percent) - 2.41 lignin (percent). Within grasses, CWC and lignin were of most significance; within legumes, lignin and tannins were most important. Silica concentration, which has been shown to affect the digestibility of temperate forages, varied with species and growth stage and did not relate consistently to DDM.

Mineral concentrations varied significantly with family, genus, species, and forage cultivar. Stage of growth effects varied with the mineral and with the type of forage. Of the major minerals, concentrations of phosphorus and sodium appeared potentially most limiting for the feeding of ruminant animals. Levels of the micro-elements were generally within the ranges recommended for animal nutrition.

Chemical Composition and Quality of Tropical Forages

R. L. Reid, Amy J. Post and F. J. Olsen

Introduction

The relatively low nutritional quality of tropical forages when compared with temperate species has been attributed to differences in the chemical composition of the plants, these differences in turn being mediated either genetically or by environmental factors. A review by Butterworth (1967) indicated that tropical grasses and legumes were consistently low in crude protein content and Bredon and Horrell (1961, 1962) concluded that under Ugandan conditions the level of digestible crude protein in many grasses was inadequate for cattle production for several months of the year. The energy, or starch equivalent, content of the grasses was thought to be adequate. By contrast, Long *et al.* (1972) found that pastures sampled from dairy farms in eastern Uganda generally contained adequate concentrations of N (an overall mean of 2.59 percent for grasses and legumes) and concluded that the primary limiting factor was pasture dry matter *per se.* In greenhouse studies, Wilson and Haydock (1971) showed that under similar environmental conditions temperate grasses contained higher concentrations of N and P in their top growth than tropical grasses; *in vitro* digestibility coefficients for the temperate forages were found to be higher than for tropicals, but it was noteworthy that *in vitro* digestible dry matter (DDM) values for several tropical grasses were in the range of 62.8-76.9 percent.

The protein concentration of temperate forages is closely related to apparent protein digestibility (Reid *et al.,* 1959). Bredon *et al.* (1963) found a similar high correlation between crude protein and digestible crude protein for grasses grown in Uganda. They also noted that protein concentration was highly correlated with dry matter and organic matter digestibility; such a relationship is less easy to rationalize, and Hacker and Minson (1972), for example, found no association between the N concentration of *Setaria* introductions in Queensland and their *in vitro* dry matter digestibility. Milford and Minson (1965) have, however, shown that the dry matter intake of certain tropical grasses decreased significantly when the crude protein level fell to less than 7 percent.

The relationship between nutritional quality and the cell wall fractions of plants has been examined extensively for temperate forages (Sullivan, 1964, 1969; Van Soest, 1967). Payne (1966), in reviewing tropical studies, concluded that crude fiber concentration was related inversely to rainfall and that fiber levels in tropical forages were consistently higher than in temperate species harvested at the same growth stage. Under conditions of controlled environment, Wilson and Ford (1971) showed that tropical grasses had a higher level of structural carbohydrate, and a lesser amount of soluble carbohydrate, than the temperate ryegrasses and that higher temperature regimes increased the cell wall concentration and depressed the *in vitro* digestibility of both classes of forage. They suggested that differences in digestibility were associated with changes in structural carbohydrate fractions.

The difficulty of applying estimates of individual components of forage plants to the prediction of nutritional quality, especially across a range of species, has been pointed out by Van Soest (1967). However, use of summative equations involving two or more plant fractions, as developed for temperate forages by Van Soest, has met with variable success when applied to tropical species. In an evaluation of grasses grown in Puerto Rico, Kayongo-Male *et al.* (1972) found that *in vitro* DDM was not highly correlated with the Van Soest regressions; acid detergent fiber (ADF) had more effect than lignin in determining digestibility, and silica and the lignin/ADF ratio were not significantly correlated with *in vitro* data. For *Panicum* species, Minson (1971) showed that the main factors affecting organic matter digestibility were the proportions of hemicellulose and cellulose, and their degree of lignification; silicon had no effect on digestibility of organic matter. Johnson *et al.* (1973), in a study of the nutritional quality of elephant grass (*Pennisetum purpureum*) grown in Peru, established significant correlations between *in vitro* DDM and the individual components ADF, hemicellulose, cellulose and lignin; in a multiple regression to predict *in vitro* digestibility, total cell-wall components (CWC) and lignin were significant factors, while protein was not. They concluded that, for this grass, the summative equation of Van Soest was not suitable for the prediction of digestibility.

In a previous study (Reid *et al.*, 1973) the relationships between *in vivo* and *in vitro* DDM of 42 grasses and 11 legumes were related to stage of growth of the plant during the five-month period of rains at Kabanyolo, Uganda. It was concluded that there were marked genus, species and varietal differences both in digestibility coefficients and in the rate of change in digestibility with maturation; *in vitro* digestibility data for 'improved' genera such as *Setaria, Panicum, Chloris, Brachiaria* were high in relation to reported digestibility values for tropical grasses, and significantly different from coefficients obtained with indigenous range species.

The purpose of the present work was to describe changes in crude protein, structural carbohydrate fractions, tannin and the mineral concentrations of the grasses and legumes, and to evaluate these components in the prediction of *in vitro* DDM. A further objective was to determine whether the use of a summative equation to predict nutritive quality offered any advantages in terms of increased accuracy and precision over that of any individual chemical component of the forage.

Experimental

Forages were grown on the Kabanyolo Experimental Farm, Makerere University, Uganda, located north of Lake Victoria. Climate is humid tropical, with annual mean maximum and minimum temperatures of 28 C and 16 C, respectively, and annual rainfall of approximately 1,300 mm, with two peaks, one occurring in April and the other in November. The driest months are January and July. The soils at Kabanyolo are classified as latosols, and are deep, highly weathered and leached, fine-textured, well-drained red soils.

Primary growth on the plots was sampled at weekly intervals for a ten-week period after plots had been cut and fertilized at the beginning of February, 1970, and at two-week intervals thereafter (cover photograph). All grass plots were treated with a 10-10-10 fertilizer at 891 kg/ha and the legumes received 446 kg 0-20-20 fertilizer per ha. The areas were watered daily until the beginning of the rains in March. Nitrogen analysis on the forage samples was run by the Kjeldahl technique. Cell wall components (CWC) or neutral-detergent fiber, acid-detergent fiber (ADF), acid-detergent lignin and silica values were determined by procedures developed by Van Soest (Goering and Van Soest, 1970). Tannin analysis was conducted by the Folin-Denis method as described by Burns (1963). Mineral analyses were run by an emission spectrographic procedure. Statistical analyses of data were run by procedures described by Snedecor (1956).

Results and Discussion

Stage of Growth Effects on Chemical Composition

It was previously shown that the *in vitro* DDM of the majority of grass and legume samples collected in Uganda declined in a linear fashion with advancing maturity of the plant (Reid *et al.*, 1973). The effect of growth stage on the structural carbohydrate and nitrogen fractions of forages associated with the decline in digestibility has been described extensively for temperate species. Sullivan (1969) summarized these trends as a continuous drop in protein, an increase in lignin during the entire growth period, and an increase in fiber to the seeding stage, with a decline thereafter. Figures 1 and 2 illustrate changes in the concentration of crude protein, CWC, ADF, acid-detergent lignin and tannin in species of *Setaria* and in a number of legumes. Table 1 is a summary of mean values for components of all forages analyzed, with an appropriate linear regression equation relating composition to days of growth. Complete data for concentrations of total nitrogen, CWC, ADF and lignin are given in Appendix Tables 1, 2, 3 and 4.

Crude Protein

Wilson and Haydock (1971) concluded that the generally low N concentration reported for tropical forages resulted from a deficiency of soil N, from an increased top growth and a consequent depletion of soil nutrients. However, they also noted that under controlled environmental conditions tropical species could contain up to 5 percent N with fertilization and Wilson (1973) found, using *Panicum maximum* var. *trichoglume,* that the ability to accumulate high levels of N did not differ between plants grown outdoors and in a humidified glasshouse. As indicated in Figure 1 and Table 1, levels of plant protein during the early vegetative period of growth were generally high in the improved grasses, with values in the *Setarias,* for example, ranging up to 30 percent. By comparison, protein levels in the indigenous grasses (e.g. *Cymbopogon, Hyparrhenia, Themeda)* on the same cutting dates and under the same level of fertilization were in the range of 11-14 percent.

There were significant differences ($P<.05$) in plant crude protein concentration due to family and to genus, but not to species or variety. Bredon and Horrell (1962) noted that there were considerable differences in protein level among varieties of grasses grown in Uganda and concluded that the differences could be of value in selecting grasses for the improvement of pastures. In later trials, however, Olsen (1972) and Soneji *et al.* (1972) observed only small differences in protein concentration between a number of

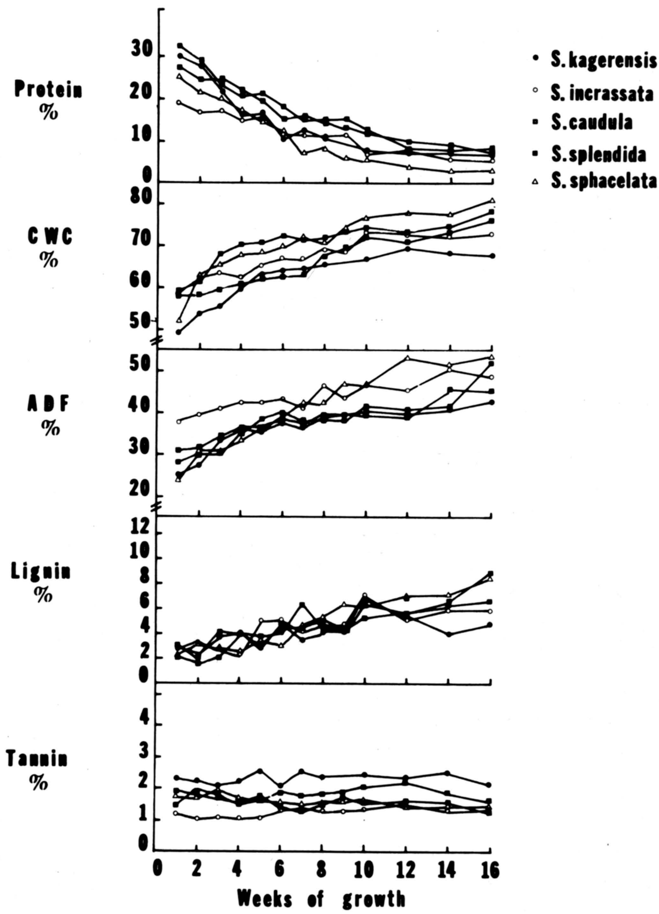

Figure 1. Change in crude protein, CWC, ADF, lignin and tannin concentration of five species of *Setaria* with advancing maturity of the grass.

species of improved grasses grown at Kabanyolo. Results in the present trials showed that the legumes had generally higher mean protein levels than the grasses and that the rate of decline in crude protein concentration with advancing maturation was less. It was of interest to note that the level and rate of change of protein in *Medicago sativa* grown under tropical conditions was similar to that recorded for alfalfa grown in the NE United States (Reid *et al.*, 1962). The rate of decline in protein concentration with age in the legumes showed considerable variability, probably associated with the difficulty of sampling the trailing foliage, but there were nevertheless rather consistent differences among legumes in protein levels (Figure 2). *Desmodium intortum* and *Stylosanthes gracilis* had low protein values, while the *Centrosema*

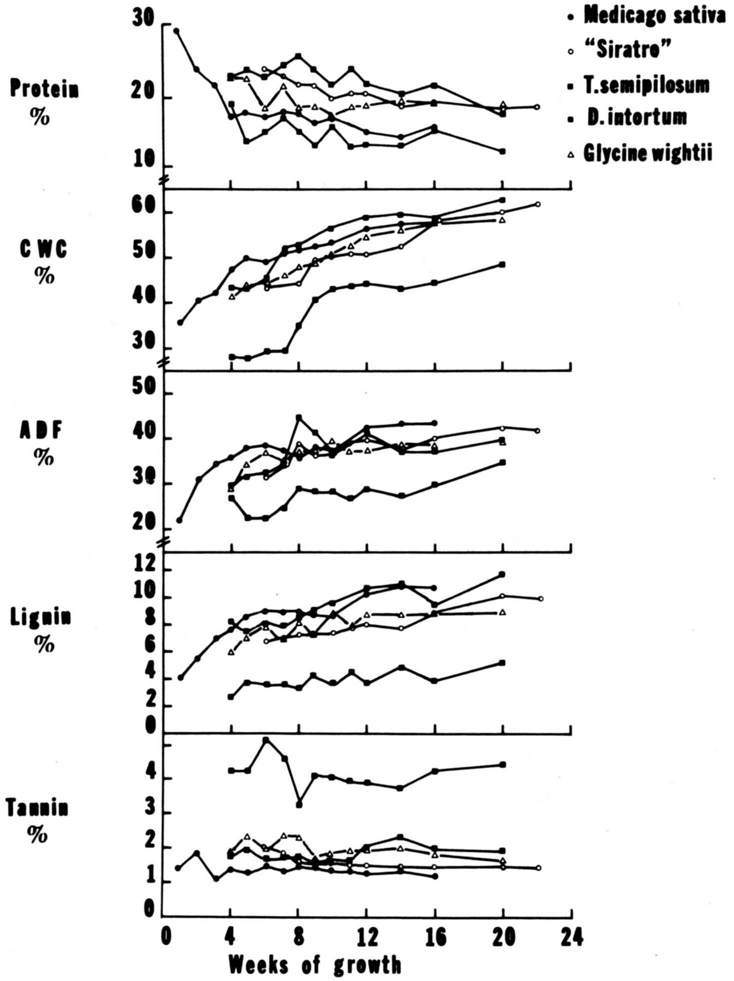

Figure 2. Change in crude protein, CWC, ADF, lignin and tannin concentration of five legume species with advancing maturity.

species and *Trifolium semipilosum* maintained a high concentration of crude protein throughout the growing season.

Among the grasses, significant genus differences were apparent in protein level. The major genera ranked in the order: *Pennisetum* > *Setaria* > *Chloris* > *Brachiaria* > *Panicum* > *Hyparrhenia* > *Cymbopogon* > *Themeda.* Within genera, *Brachiaria mutica* had higher levels of crude protein than the other *Brachiaria* species during the first six weeks of growth; of the *Setarias, Setaria splendida* contained higher concentrations of protein than *Setaria sphacelata* and *Setaria incrassata* at all cutting dates over the sampling period. It may be noted that orchardgrass (*Dactylis glomerata),* while it grew poorly at Kabanyolo, contained the highest mean protein level of all grasses examined.

Table 1
Chemical composition (means) and relationship between composition and number of days of growth for grasses and legumes

Species	Number of samples	Crude protein	Regression equation	CWC
		%		%
Grasses:				
Andropogon gayanus	13	9.7	Y=14.49-0.09X	73.8
Beckeropsis uniseta	13	14.4	Y=21.45-0.13X	63.8
Brachiaria brizantha	12	13.2	Y=22.56-0.20X	66.6
Brachiaria decumbens	12	10.7	Y=19.56-0.16X	68.5
Brachiaria humidicola	13	12.2	Y=17.83-0.11X	71.1
Brachiaria mutica	10	15.0	Y=29.89-0.28X	72.0
Brachiaria ruziziensis	13	13.0	Y=21.83-0.17X	64.1
Cenchrus ciliaris	13	11.4	Y=19.19-0.15X	74.7
Chloris gayana cv. 'Masaba'	13	13.8	Y=22.09-0.16X	71.8
Chloris gayana cv. 'Mbarara'	13	13.1	Y=24.27-0.21X	73.7
Chloris gayana cv. 'Pokot'	13	13.8	Y=21.69-0.15X	72.9
Cymbopogon afronardus	13	9.6	Y=12.81-0.06X	75.7
Cymbopogon giganteus	13	9.8	Y=13.44-0.07X	75.0
Cynodon dactylon	12	13.7	Y=20.16-0.11X	71.7
Dactylis glomerata	5	19.2	Y=23.20-0.06X	59.1
Digitaria decumbens	12	15.9	Y=25.99-0.18X	61.0
Digitaria uniglumis	13	10.6	Y=13.34-0.05X	63.2
Echinochloa pyramidalis	11	14.1	Y=20.58-0.15X	69.1
Hyparrhenia cymbaria	11	12.0	Y=18.97-0.16X	70.1
Hyparrhenia diplandra	13	9.6	Y=14.38-0.09X	74.4
Hyparrhenia lintoni	13	8.5	Y=12.91-0.08X	74.8
Hyparrhenia rufa	13	9.8	Y=15.32-0.11X	72.3
Melinis minutiflora	12	11.2	Y=23.24-0.17X	72.9
Panicum coloratum	12	13.7	Y=22.70-0.19X	65.5
Panicum coloratum var. *makarikariensis*	13	11.7	Y=19.34-0.15X	72.3
Panicum maximum cv. 'Creeping Embu'	12	11.5	Y=22.82-0.21X	71.4
Panicum maximum cv. 'Likoni'	13	13.4	Y=22.81-0.18X	69.7
Panicum maximum cv. 'Makueni'	13	14.9	Y=24.35-0.18X	72.0
Panicum maximum var. *trichoglume*	13	14.5	Y=24.81-0.20X	69.4
Panicum repens	12	12.7	Y=18.84-0.11X	69.8
Paspalum commersonii	13	9.1	Y=11.15-0.04X	73.2
Paspalum urvillei	13	11.0	Y=13.42-0.05X	74.8
Pennisetum clandestinum	13	17.0	Y=27.39-0.20X	64.3
Pennisetum purpureum	12	15.4	Y=21.37-0.11X	66.3
Setaria caudula	13	16.6	Y=27.05-0.20X	65.9
Setaria incrassata	13	12.4	Y=19.44-0.13X	67.4
Setaria kagerensis	12	14.9	Y=25.54-0.21X	62.4

Regression equation	ADF	Regression equation	Lignin	Regression equation	Tannin	Regression equation
	%		%		%	
Y=71.41+0.05X	42.8	Y=36.87+0.11X	5.2	Y=3.60+0.03X	2.3	Y=2.88-0.01X
Y=54.93+0.16X	36.0	Y=31.06+0.09X	4.3	Y=3.39+0.02X	1.7	Y=1.76-0.001X
Y=57.09+0.20X	34.2	Y=25.83+0.18X	4.0	Y=2.33+0.04X	1.4	Y=1.54-0.004X
Y=58.28+0.19X	36.2	Y=27.17+0.17X	4.3	Y=2.33+0.04X	1.5	Y=1.66-0.003X
Y=64.60+0.13X	38.8	Y=34.50+0.08X	4.6	Y=2.54+0.04X	1.5	Y=1.26+0.005X
Y=62.39+0.18X	36.7	Y=25.48+0.21X	4.9	Y=2.88+0.04X	1.6	Y=1.71-0.003X
Y=54.70+0.18X	35.3	Y=25.06+0.20X	3.8	Y=2.38+0.03X	1.4	Y=1.51-0.002X
Y=62.14+0.24X	44.2	Y=32.56+0.22X	5.5	Y=1.68+0.07X	1.2	Y=1.27-0.001X
Y=65.09+0.13X	41.0	Y=32.05+0.17X	5.4	Y=2.81+0.05X	1.1	Y=1.14-0.0004X
Y=65.17+0.16X	42.1	Y=31.28+0.21X	5.7	Y=2.44+0.06X	1.2	Y=1.25-0.001X
Y=68.74+0.08X	41.0	Y=32.60+0.16X	4.8	Y=1.64+0.06X	1.0	Y=1.10-0.001X
Y=70.82+0.09X	43.0	Y=39.11+0.08X	6.4	Y=4.39+0.04X	1.6	Y=1.42+0.003X
Y=71.09+0.07X	40.0	Y=35.68+0.08X	5.5	Y=3.98+0.03X	2.3	Y=2.05+0.005X
Y=66.82+0.09X	35.9	Y=31.79+0.07X	5.3	Y=3.04+0.04X	1.2	Y=1.18+0.0001X
Y=52.70+0.10X	32.7	Y=28.88+0.06X	5.3	Y=5.11+0.003X	2.5	Y=2.88-0.006X
Y=54.47+0.12X	35.7	Y=30.89+0.09X	4.8	Y=2.88+0.03X	2.0	Y=2.04-0.001X
Y=60.65+0.05X	39.3	Y=35.82+0.06X	4.9	Y=3.93+0.02X	3.2	Y=3.47-0.005X
Y=62.87+0.15X	37.5	Y=33.75+0.09X	3.6	Y=2.25+0.03X	1.6	Y=1.55+0.001X
Y=65.16+0.12X	39.4	Y=33.50+0.14X	5.0	Y=2.63+0.06X	1.6	Y=1.64-0.002X
Y=71.19+0.06X	43.8	Y=39.81+0.08X	5.0	Y=3.52+0.03X	1.8	Y=1.45+0.007X
Y=72.03+0.05X	44.8	Y=40.09+0.09X	6.3	Y=4.05+0.04X	2.1	Y=1.73+0.007X
Y=67.95+0.08X	44.4	Y=36.31+0.15X	5.8	Y=3.56+0.04X	2.3	Y=2.76-0.008X
Y=65.34+0.11X	41.2	Y=28.63+0.18X	4.8	Y=1.49+0.05X	2.1	Y=2.22-0.002X
Y=56.46+0.19X	38.6	Y=27.44+0.23X	5.2	Y=3.03+0.05X	1.6	Y=1.59-0.001X
Y=70.34+0.04X	36.5	Y=32.56+0.07X	5.1	Y=3.77+0.03X	1.3	Y=1.07+0.004X
Y=61.38+0.19X	42.2	Y=31.42+0.20X	5.5	Y=1.55+0.07X	1.6	Y=1.73-0.003X
Y=63.35+0.12X	43.0	Y=33.00+0.19X	5.9	Y=2.96+0.06X	1.5	Y=1.63-0.002X
Y=65.86+0.12X	42.8	Y=33.13+0.18X	5.6	Y=3.73+0.04X	1.5	Y=1.51-0.001X
Y=61.79+0.15X	40.9	Y=30.52+0.20X	6.2	Y=3.50+0.05X	1.4	Y=1.59-0.003X
Y=64.90+0.09X	34.2	Y=30.40+0.07X	4.8	Y=3.89+0.02X	1.6	Y=1.66-0.002X
Y=69.36+0.07X	41.1	Y=39.69+0.03X	7.5	Y=6.66+0.02X	3.7	Y=3.46+0.005X
Y=71.90+0.06X	43.2	Y=41.74+0.03X	4.2	Y=3.45+0.02X	2.1	Y=2.19-0.002X
Y=53.82+0.20X	32.7	Y=25.62+0.14X	4.6	Y=2.89+0.03X	1.6	Y=1.92-0.006X
Y=57.07+0.17X	35.9	Y=30.70+0.10X	4.0	Y=3.02+0.02X	1.2	Y=1.29-0.002X
Y=56.16+0.19X	37.9	Y=31.05+0.13X	4.3	Y=2.14+0.04X	1.8	Y=1.66+0.002X
Y=59.69+0.15X	43.7	Y=38.51+0.10X	4.6	Y=2.83+0.03X	1.2	Y=1.09+0.002X
Y=53.84+0.17X	36.4	Y=29.38+0.14X	4.1	Y=3.05+0.02X	2.3	Y=2.23+0.001X

Table 1 (cont.)

Species	Number of samples	Crude protein	Regression equation	CWC
		%		%
Grasses (cont.)				
Setaria sphacelata	13	11.6	Y=23.04-0.22X	70.8
Setaria splendida	13	17.9	Y=29.65-0.23X	70.9
Sorghum sudanense	12	10.9	Y=19.30-0.15X	66.3
Themeda gigantea	13	9.9	Y=14.32-0.09X	77.0
Themeda triandra	13	9.1	Y=14.53-0.09X	77.0
Legumes:				
Centrosema plumieri	12	21.2	Y=25.39-0.06X	52.0
Centrosema pubescens	12	22.5	Y=25.37-0.04X	56.2
Desmodium intortum	11	14.7	Y=17.01-0.03X	53.3
Desmodium uncinatum	11	17.7	Y=21.47-0.05X	54.2
Glycine wightii	12	19.4	Y=21.54-0.03X	50.0
Medicago sativa	13	18.5	Y=23.86-0.10X	49.8
Phaseolus atropurpureus cv. 'Siratro'	11	20.6	Y=24.76-0.05X	51.4
Pueraria phaseoloides	12	18.8	Y=22.64-0.05X	49.3
Pueraria javanica	12	18.6	Y=22.20-0.05X	52.2
Stylosanthes gracilis	9	16.3	Y=16.62-0.01X	56.5
Trifolium semipilosum	12	22.8	Y=26.84-0.06X	38.1

Y = % chemical component in dry matter of herbage.
X = number of days of growth after clipping plots on February 2, 1970.

Bredon and Horrell (1961) found that the protein content of grasses collected at Kawanda and Entebbe declined in a curvilinear fashion with maturation, and that protein became the primary limiting factor for animal production after the first two months of growth. Similarly in this study the rate of decline in crude protein concentration in the grasses was best described as a curvilinear function. Using the recommendation of 5.9 percent total protein for the maintenance of the pregnant beef cow (N.R.C., 1970), the majority of grasses analyzed in this study supplied this level until approximately the twelfth week of growth. Most grasses, with a moderate amount of fertilization, would also meet the higher requirements (10 percent total protein) of growing cattle for a period of approximately eight weeks after the beginning of the rains.

Cell-wall fractions

The high level of fiber found in tropical forages has been commented upon by many authors. Generally, fiber has been estimated as crude fiber by the classical Weende method, and Butterworth and Diaz (1970) noted that until recently few other measures of structural components of tropical forages were available.

Bailey (1973), in reviewing the literature on structural carbohydrates in plants, concluded that tropical grasses had higher levels of cellulose in the leaf

Regression equation	ADF	Regression equation	Lignin	Regression equation	Tannin	Regression equation
	%		%		%	
Y=59.67+0.21X	40.9	Y=26.24+0.28X	4.8	Y=1.61+0.06X	1.6	Y=1.88-0.006X
Y=63.62+0.14X	38.1	Y=29.23+0.17X	5.0	Y=2.19+0.05X	1.6	Y=1.80-0.004X
Y=57.90+0.16X	41.2	Y=32.74+0.16X	5.5	Y=2.54+0.05X	1.8	Y=2.02-0.004X
Y=73.60+0.07X	43.7	Y=39.77+0.08X	4.7	Y=2.37+0.04X	1.7	Y=1.76-0.0002X
Y=73.49+0.06X	44.2	Y=39.85+0.07X	5.9	Y=3.82+0.04X	1.5	Y=1.60-0.001X
Y=41.27+0.15X	35.8	Y=31.19+0.06X	8.0	Y=6.76+0.02X	2.5	Y=2.79-0.005X
Y=43.29+0.16X	36.1	Y=30.76+0.06X	9.3	Y=7.21+0.03X	1.6	Y=1.61-0.001X
Y=40.77+0.18X	36.5	Y=32.02+0.06X	8.9	Y=9.07-0.01X	4.1	Y=4.29-0.002X
Y=39.36+0.21X	39.8	Y=30.76+0.13X	11.1	Y=6.51+0.07X	2.7	Y=3.10-0.005X
Y=38.31+0.16X	36.3	Y=32.01+0.06X	7.9	Y=6.36+0.02X	1.9	Y=2.13-0.003X
Y=39.83+0.19X	36.6	Y=29.07+0.14X	8.3	Y=5.47+0.05X	1.4	Y=1.39+0.0001X
Y=36.68+0.17X	38.1	Y=31.49+0.08X	8.0	Y=5.47+0.03X	1.5	Y=1.87-0.004X
Y=36.86+0.17X	37.7	Y=32.65+0.07X	8.6	Y=6.29+0.03X	2.9	Y=3.42-0.007X
Y=40.42+0.17X	39.4	Y=33.99+0.08X	8.4	Y=6.34+0.03X	2.8	Y=3.10-0.005X
Y=47.90+0.09X	34.5	Y=31.35+0.03X	8.5	Y=9.03-0.01X	2.6	Y=3.32-0.008X
Y=23.50+0.20X	27.1	Y=21.12+0.08X	3.6	Y=2.36+0.02X	1.8	Y=1.61+0.003X

than the festucoid grasses and that, where tropical and temperate species were grown under the same environmental conditions, the tropical species contained greater amounts of hemicellulose.

A direct comparison of this nature was possible only on a limited basis in this study. However, it was noted that mean levels of CWC and ADF for both grasses and legumes were not markedly different from those reported for temperate species (Table 2). Van Soest (1971) cited mean CWC values of 52, 71 and 68 percent for all analyses of alfalfa, brome and timothy forages, respectively, and ADF levels of 40, 38 and 43 percent. With the exception of *Trifolium semipilosum* (Kenya clover), which had markedly lower CWC and ADF concentrations over the complete growth period (Figure 2), the mean values for CWC and ADF for the tropical legumes fell within the ranges 49-57 and 34-40 percent, respectively. The CWC content of *Medicago sativa* was at the lower end of the range, but the ADF concentration was not significantly different from that of the other legumes.

Moore and Mott (1973), in a review of the quality of tropical forages, concluded that the ranges of crude fiber, ADF and lignin in tropical grasses were similar to those in temperate species, but that the concentration of CWC in tropical grasses was consistently higher than in the temperates. In this study, the grasses contained higher levels of CWC and slightly higher levels of ADF than the legumes, and there were significant genus and species effects on

Table 2
Comparison of mean levels of CWC and ADF
in temperate and tropical forages

Temperate (Van Soest, 1971)	CWC (%)	ADF (%)
Species:		
Brome*	71	38
Orchardgrass*	69	40
Timothy*	68	43
Sudangrass*	68	43
Alfalfa*	52	40
Red Clover*	56	41
Tropical		
All grasses (N = 520)	70.0	39.6
All legumes (N = 127)	51.2	36.2

*All analyses.

both components. Generally, the majority of grasses had a mean CWC content in the range of 65-75 percent, and a mean ADF content in the range of 35-45 percent. Interestingly, the temperate species *Dactylis glomerata* contained the lowest levels of CWC and ADF but, as mentioned previously, growth of this grass at Kabanyolo was poor and the number of samples was limited. The range-type grasses (*Cymbopogon, Hyparrhenia, Themeda)* tended to contain high levels of CWC and ADF. Low CWC concentrations were apparent in *Digitaria, Pennisetum,* and in species of *Setaria* and *Brachiaria.* In confirmation of the observation of Bailey (1973), the levels of hemicellulose (calculated as the difference between CWC and ADF) in the tropical grasses were high, and the proportion of hemicellulose in CWC generally declined with increasing age of the plant.

Regression analysis indicated that the increase in CWC and ADF with maturation in the grasses was linear, and that the effects of genus, species, and variety on rate increase of both fractions were nonsignificant. The pattern for crude fiber increase in tropical grasses has more frequently been described as curvilinear, with an initial sharp rise in fiber concentration followed by a levelling out (e.g. Bredon and Horrell, 1961). Johnson *et al.* (1973), however, noted a continuous increase in concentrations of CWC, ADF, cellulose, and lignin in *Pennisetum purpureum* harvested in different seasons and at different growth stages in Peru, and Gomide *et al.* (1969) observed a similar increase in crude fiber and cellulose percentage to approximately twenty weeks of age in some, although not all, tropical grasses grown in Brazil.

French (1957) concluded that, under the erratic rainfall conditions of the tropics, grasses developed a high lignin concentration at an earlier vegetational stage than did temperate species. Under conditions of these trials, where moisture was not a limiting factor, the extent and mode of lignification of the grasses was apparently similar to that under temperate conditions. Lignin levels at the early stages of growth (up to three weeks) were generally in the range of 2-4 percent and increased thereafter in a linear fashion to values of 6-10 percent at 16-18 weeks of age. Within the grasses there were significant genus and species effects on lignin accumulation. The major difference, however, was the markedly higher concentration of lignin in the legumes than in the grasses, mean values in the legumes generally lying in the range of 8-10 percent. This difference has been observed frequently in temperate species (e.g. Sullivan, 1964). An exception among the tropical legumes was the species *Trifolium semipilosum* where, as was the case with the CWC and ADF concentrations, the level of lignin was consistently lower than that of the other legumes (Figure 2). For *Medicago sativa* there was a definite trend for all cell-wall fractions, CWC, ADF and lignin, to increase most rapidly to 4-6 weeks of age, then to increase at a slower rate.

Tannin

An analysis for tannins was carried out in light of the known growth depressing and toxic properties of this group of polyphenolic compounds. It has been demonstrated that the presence of tannins may lower both the digestibility and intake of forages by ruminants. Further, in a study of temperate and tropical legumes, Jones and Lyttleton (1971) suggested that the infrequent occurrence of bloat in animals grazing tropical legumes might be due to a higher concentration of tannins or protein-precipitating substances in the plant. The tannin content of the grasses was found to be uniformly rather low, of the order of 1-2 percent expressed as "tannic acid equivalent." Only two species, *Digitaria decumbens* and *Paspalum commersonii,* had mean values higher than 3 percent. Tannin levels in the legumes were slightly higher, but varied from the consistently low concentrations found in *Medicago sativa* to the quite high levels in *Desmodium intortum.* In some species there was a slight decline in the concentration of tannins as the plant matured, but overall, growth stage had relatively little effect on concentration.

Silica

Silica has been associated with a depression of digestibility in temperate forages, and Van Soest and Jones (1968) demonstrated a significant negative correlation between the lignin and Si concentration of temperate grasses. Kayongo-Male *et al.* (1976) found that the Si concentration of grasses harvested in Puerto Rico did not vary consistently with other structural components and that the relationship between silica concentration and digestibility varied with genus of grass. Silicon in these trials was determined as ADF silica (Goering and Van Soest, 1970) and effects of growth period upon Si concentrations are illustrated for a limited number of grasses in Figure 3. The data indicate that there were marked species differences in patterns of Si distribution with advancing maturity in the tropical grasses. In fact, three general trends were observed; one, illustrated by *Setaria kagerensis,* in which the level of SiO_2 increased with age; another, illustrated by *Hyparrhenia rufa,* in which silica declined; and a third, illustrated by *Brachiaria ruziziensis* and *Panicum coloratum,* in which the concentration of silica was low and did not change appreciably as the plant matured. The silica concentration of the grasses ranged from 0.47 to 4.75 percent, with a mean concentration of 2.43 percent. The silica level of the legumes was lower ($P<.05$), ranging from 0.05 to 2.17 percent, with a mean concentration of 1.08 percent. Of the legumes, alfalfa had particularly low concentrations of silica, ranging from 0.05 to 0.52 percent.

Minerals

French (1957) has referred to the generally low levels of minerals, particularly of P and Na, found in mature tropical pastures, and Fleming (1973), in a review

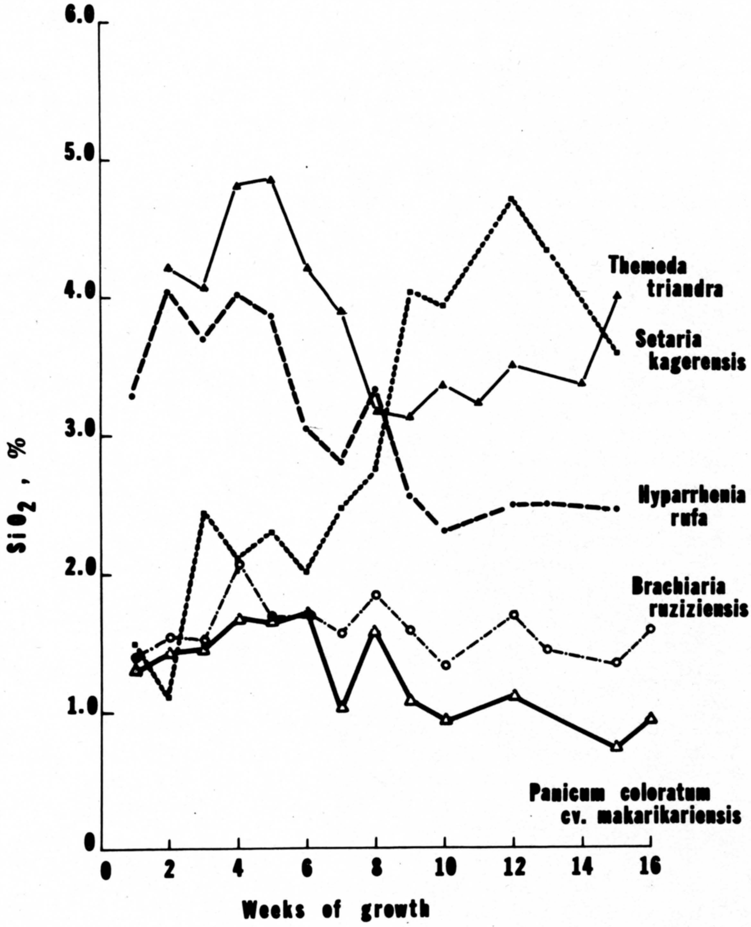

Figure 3. Silica concentration as affected by weeks of growth in five grass species.

of the mineral composition of tropical and sub-tropical grasses, suggested that the Ca and P levels appeared to be lower than in temperate grasses at an equivalent growth stage, although concentrations of Mg and micro-elements were similar. Gomide *et al.* (1969) observed a significant decrease in the concentrations of K, P, Mg, Cu, and Fe with advancing maturity in grasses grown in Brazil, with no consistent change in the level of Ca.

Figure 4 summarizes mean values for the concentration of several minerals in the total population of grasses and legumes, as they relate to N.R.C. (1971) recommendations for dairy cows producing moderate levels (<20 kg) of milk. The requirement for Mg has been placed at 0.20 percent, rather than 0.10 percent. The general trend for both grasses and legumes was to supply adequate levels of Ca, Mg, K, Cu, and Zn, while Na was deficient in both groups of forages and P was at marginal concentration in the grasses.

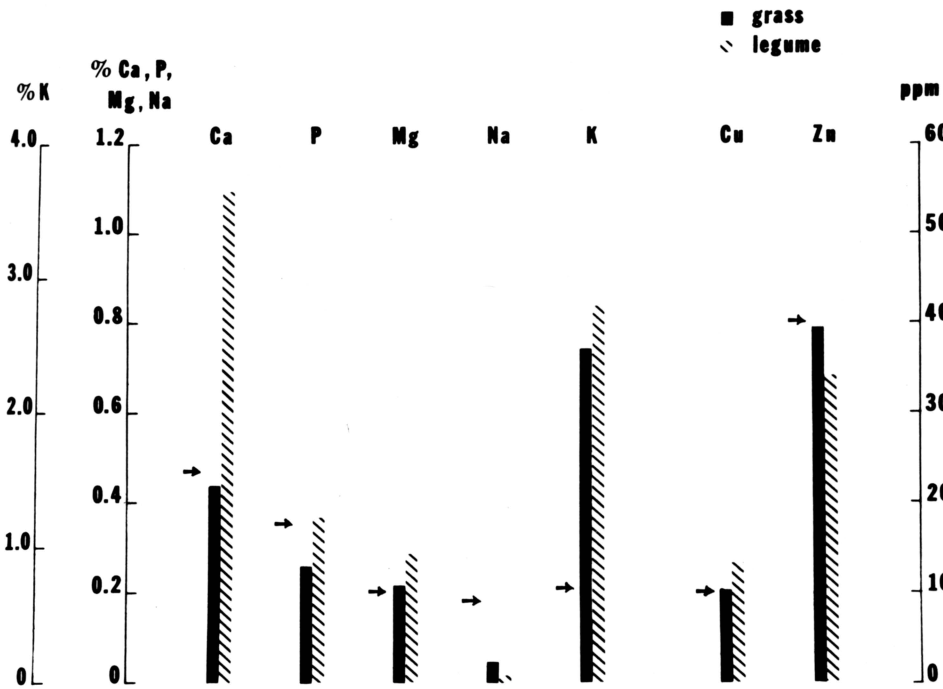

Figure 4. Mean mineral concentrations in total populations of grasses and legumes, in relation to N.R.C. (1971) recommendations for a dairy cow producing moderate amounts (<20 kg) of milk.

There were significant (P<.05) differences in mineral concentrations due to family, genus, species, and variety of forage, as has been observed by Fleming (1973). An example of this is shown in Figure 5, which gives mean values for Ca, P, Mg, and Na in five species of *Brachiaria*. While P levels were reasonably constant, there were marked differences in concentrations of Ca, Mg and Na. Mean values for concentrations of major and minor minerals for individual forage species over all stages of maturity are given in Appendix Tables 5 and 6. Concentrations of Ca in the grasses, grown on the same soil, ranged from 0.16 percent (*Cenchrus ciliaris*) to 0.86 percent (*Beckeropsis uniseta*); for P, the range was lower, 0.20 percent (*Panicum coloratum*) to 0.40 percent (*Dactylis glomerata*). Mean Mg concentrations ranged from 0.10 percent (*Andropogon gayanus* and *Cenchrus ciliaris*) to 0.36 percent (*Digitaria decumbens* and *Echinochloa pyramidalis*), and K levels from 1.45 percent (*Themeda gigantea*) to 3.87 percent (*Echinochloa pyramidalis*). Of the micro-elements, fairly wide ranges were noted for Mn, 62 ppm (*Cenchrus ciliaris*) to 495 ppm (*Dactylis glomerata*), and for Mo, 0.58 ppm (*Andropogon gayanus*) to 2.28 ppm (*Digitaria decumbens*). A lower range was observed for Cu, 8-13 ppm, and Zn, 26-57 ppm.

Effects of stage of maturity on the mean concentrations of Ca, P, Mg, Na and K in the grasses and legumes are summarized in Figure 6. For the majority of

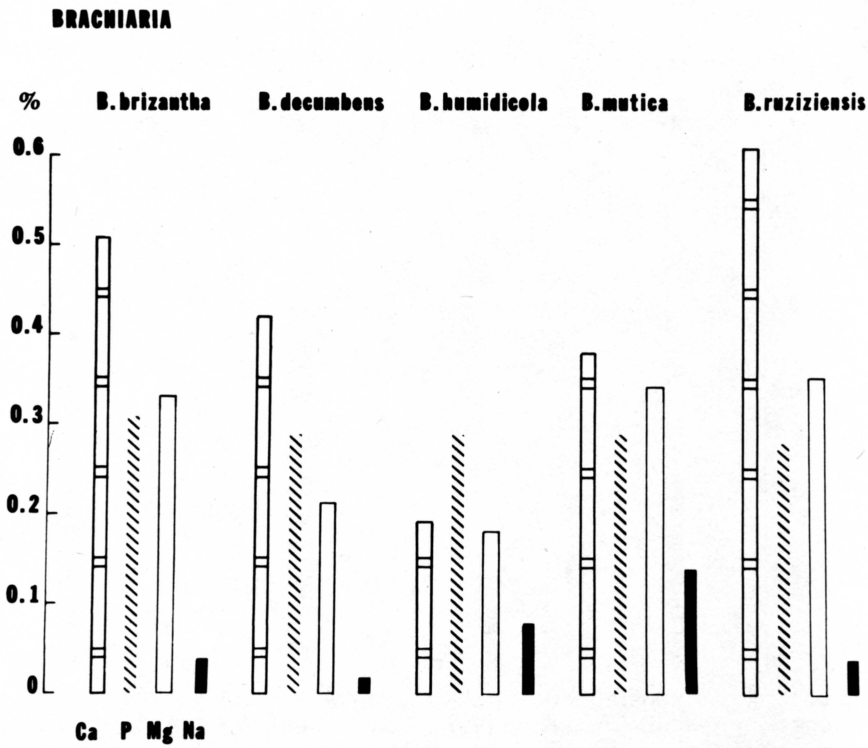

Figure 5. Differences between *Brachiaria* species in concentrations of Ca, P, Mg, Na. Values are means for all growth stages of the grass.

species, no well-defined trends in Ca level were evident due to age of the plant, in agreement with Gomide *et al.* (1969). Of the grasses, *Cenchrus ciliaris* and *Brachiaria humidicola* had the lowest mean Ca concentration, with values of 0.16 and 0.19 percent, respectively. These values are lower than Ca levels reported by Long *et al.* (1970, 1972) for farms in eastern Uganda. The legumes as a group had consistently higher Ca concentrations than the grasses. Alfalfa growing under tropical conditions had a lower mean Ca concentration (0.81 percent) than any of the other legumes.

The percentage of P declined with maturation in both grasses and legumes. The values are comparable to those reported for forages in eastern and western areas of Uganda, but lower than those obtained in the lakeshore region (Long *et al.*, 1969, 1970, 1972). The values for grasses were, however, appreciably higher at all growth stages than data for P in indigenous grasses grown in Ghana, without fertilization (Sen and Mabey, 1965), or for fertilized grasses grown in Brazil (Gomide *et al.*, 1969). The legumes averaged consistently higher in P concentration than the grasses.

Magnesium concentration in the grasses increased to approximately 4 to 6 weeks of growth, and then showed little change to 18 weeks. Magnesium levels in the legumes were higher than in the grasses and decreased slightly with

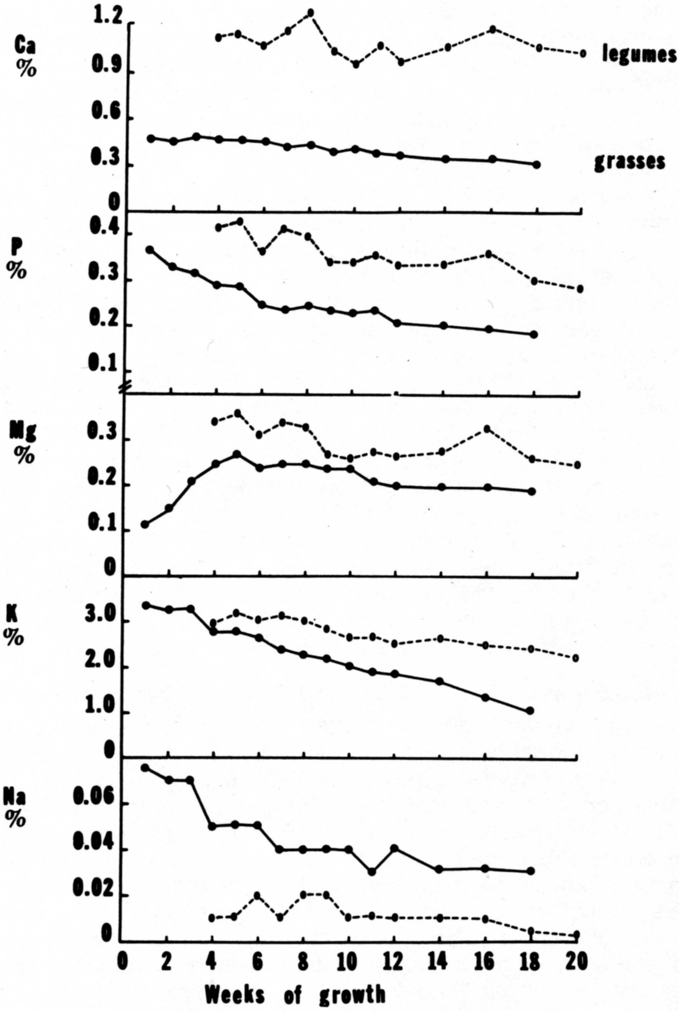

Figure 6. Changes in mineral concentration with maturation. Values are means for all genera, species and varieties within grasses and legumes.

age, with the exception of alfalfa, which increased. There were marked species differences in Mg accumulation in both grasses and legumes. Of the grasses, *Andropogon gayanus* and *Cenchrus ciliaris* had the lowest values (a mean of 0.10 percent Mg in each species), while *Centrosema plumieri* had the highest concentration (0.48 percent) among the legumes.

Potassium declined with maturity and the rate of decline was greater with the grasses than with the legumes; the improved tropical grasses had higher K concentrations than the range or indigenous species and the improved grass values were much the same as for the legumes. The Na concentrations were uniformly low, and 96 percent of the values obtained in this study fell below the recommended level of 0.18 percent in the diet of lactating dairy cows (N.R.C., 1971). *Setaria splendida* was the only grass which contained a mean value (0.19 percent Na) slighly higher than this requirement. There was a trend for Na concentrations in the grasses to decrease with age of the plant. Sodium levels in the legumes were lower than in the grasses and showed little change with maturation.

Mean concentrations of Cu, Zn, Mn, and Mo in all grasses were 10, 39, 143, and 1.1 ppm, respectively. In the legumes, the concentrations were 13, 34, 99, and 1.9 ppm, respectively. The Cu concentrations tended to decrease with increasing maturity and the legumes, generally, had higher levels of Cu than the grasses. Long *et al.* (1972) found that the Zn content of several pasture species in eastern Uganda averaged 21 ppm, and recommended supplementation of Zn in the diet. De Sousa (1978) observed a range of Zn concentrations from 19 to 39 ppm in forage in the Mato Grasso, Brazil, and concluded that liver Zn levels in grazing cattle from the area were deficient. Mean values for Zn in this study ranged from 26 to 57 ppm, and the concentration of Zn did not change markedly with age of the plant. All forages studied, except alfalfa, contained adequate (40 ppm) Mn levels. Changes in Mn level with sampling period were inconsistent, with some species, e.g., *Setaria caudula, Setaria splendida, Brachiaria brizantha,* showing a decrease in Mn concentration and others, e.g., *Cymbopogon afronardus, Digitaria decumbens,* showing an increase. The Mo values were quite variable, although there was a general trend for Mo concentrations to decrease with increasing maturity of the forage.

Relationship Between *In vitro* DDM and Chemical Composition

In a review of the use of equations based on standard chemical procedures to predict the nutritional quality of tropical grasses, Butterworth and Diaz (1970) concluded that while the apparent digestibility of protein could be derived with reasonable accuracy, the accuracy of prediction of TDN was low. Only 27 percent of total variance could be accounted for by an equation based on crude protein, crude fiber and ether extract. They suggested the need for development of more sophisticated methods of analyzing plant constituents. Van Soest (1967, 1971), in considering the application of detergent extraction procedures to feed evaluation, recommended the use of lignin for prediction of the digestibility of individual plant species and the summative equation for mixtures. He also pointed out that the latter system, which involves the determination of CWC, ADF, lignin, silicon and indigestible protein, may not be feasible where facilities are limited. Data were therefore analyzed by both simple and multiple correlation and regression analysis to determine whether individual analytical components might be used with acceptable accuracy to predict DDM, or whether some form of summative equation provided a significant improvement in the accuracy of prediction.

Figure 7 presents scatter diagrams of *in vitro* DDM (%) plotted against percentage crude protein, CWC, ADF and lignin in grasses and legumes. In order to minimize the effect of stage of growth or date of cutting *per se* on the relationship between DDM and individual components, analysis of of variance and covariance was run on plot means to determine correlations by source of variation. Correlation coefficients between components in the model are summarized in Table 3. It will be noted from figure 7 that, as with forages

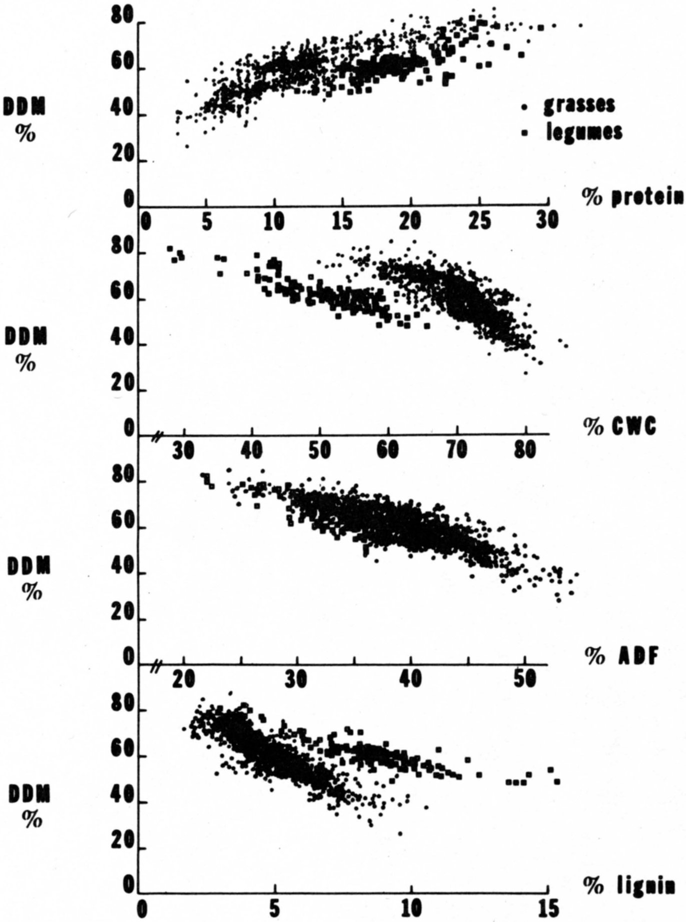

Figure 7. Relationship between *in vitro* DDM and crude protein, CWC, ADF and lignin concentration of populations of grasses and legumes.

grown in temperate conditions, regressions between *in vitro* DDM and acid-detergent lignin were significantly different for grasses and legumes. This difference applied also to CWC. Calculated regression equations between DDM and content of either crude protein or ADF were not significantly different for grasses and legumes. Sullivan (1964), in contrast, found that in comparing populations of alfalfa and different grasses, the regressions between DDM and crude protein, crude fiber or detergent fiber were different for the two classes of forage.

The use of crude protein in the estimation of DDM, digestible energy or TDN has generally been discounted due to the high errors of prediction, although workers in Uganda have found the relationship to be sufficiently high to be useful in assessing nutritional quality (Bredon *et al.*, 1963; Marshall *et al.*, 1969). A correlation coefficient of +0.46 between DDM and

Table 3
Correlation coefficients and standard errors of estimate ($s_{y.x}$) between *in vitro* DDM and chemical components of grasses and legumes. Analysis of means.

IN VITRO DDM (%)

	Protein	$s_{y.x}$	CWC	$s_{y.x}$	ADF	$s_{y.x}$	Lignin	$s_{y.x}$	Tannin	$s_{y.x}$	Hemicellulose (CWC-ADF)	$s_{y.x}$
All forages	+0.46**	±4.63	-0.54**	±4.40	-0.62**	±4.10	-0.32*	±4.94	-0.07	±5.21	-0.35**	±4.88
Genus	+0.62**		-0.81**		-0.78**		-0.81**		-0.16		-0.42*	
Species	+0.11		-0.58**		-0.07		-0.58**		-0.17		-0.50*	
Variety	-0.38		-0.51		-0.01		-0.30		+0.50		-0.41	
Grasses	+0.47**	±4.37	-0.72**	±3.42	-0.55**	±4.12	-0.68**	±3.72	-0.01	±4.94	-0.41**	±4.51
Genus	+0.62**		-0.78**		-0.75**		-0.74**		+0.08		-0.40	
Species	+0.14		-0.56*		-0.07		-0.63**		-0.28		0.46*	
Variety	-0.38		-0.51*		-0.01		-0.30		+0.50		-0.41	
Legumes	+0.57	±4.99	-0.89**	±2.73	-0.79**	±3.67	-0.94**	±2.04	-0.49	±5.27	-0.50	±5.25
Genus	+0.63		-0.89**		-0.84**		-0.98**		-0.62		-0.47	
Species	-0.25		-0.86		-0.02		-0.38		+0.41		-0.91*	

*Significant at $P<.05$.
**Significant at $P<.01$.

percent crude protein for all forages was significant, although a standard error of estimate ($s_{y.x}$) value of ± 4.63 indicated that protein would not be a suitable predictor for DDM. The similarity of the $s_{y.x}$ values between the total population and the populations of grasses and legumes suggested that there would be little advantage to considering the classes of forage separately.

Van Soest (1971) stated that the level of CWC in temperate forages was important in determining intake but that it was not highly related to digestibility. However, Johnson *et al.* (1972) and Gonzalez *et al.* (1972) noted a significant negative correlation between DDM and percent CWC in tropical forages; the former group suggested a curvilinear function for the relationship in *Pennisetum purpureum.* Within both grass and legume families there was a highly significant negative correlation between *in vitro* DDM and CWC, and the differences in regression equations and $s_{y.x}$ values between families and the total population of forages suggested the desirability of treating grasses and legumes separately. The smaller $s_{y.x}$ estimates within families indicated some improvement in the use of CWC over crude protein in the prediction of DDM.

Moore and Mott (1973) found that the best single chemical predictor of organic matter digestibility among species in a population of Florida grasses was lignin ($s_{y.x} \pm 4.50$). The high correlation coefficient (-0.94) and low $s_{y.x}$ (± 2.04) between *in vitro* DDM and lignin within the legumes indicated that lignin concentration might be a useful predictor of DDM in this class of forages. Across all forages, however, the $s_{y.x}$ value was higher than that obtained with crude protein, CWC or ADF individually. Kayongo-Male *et al.* (1972) showed that ADF content was more important than lignin in determining digestibility in Puerto Rican grasses. In this study the $s_{y.x}$ values for the *in vitro* DDM and ADF regressions were higher than for the lignin relationships within both grass and legume families, although over all forages the correlation coefficient (-0.62) between DDM and ADF was the highest of the individual coefficients obtained. It might be concluded that, of the components examined, no single constituent was suitable for the prediction of digestibility across all forages, but that within the family of legumes either lignin or CWC gave acceptable accuracy of prediction.

Stepwise multiple regressions for the prediction of *in vitro* DDM across all forages and within families were run using the following chemical components: crude protein, CWC, ADF, lignin, L/ADF, hemicellulose, cell solubles (100-CWC), silica, and tannin. The significance of components affecting DDM, and regression equations relating DDM to composition, are summarized in Table 4. The lack of effect of silica on DDM confirmed the observations of Minson (1971), using cultivars of *Panicum.* For the total population of forages, the most important single component affecting DDM was ADF, accounting for 38 percent of the variability. A multiple regression equation including CWC and lignin improved the proportion of variability accounted for from 38 to 74 percent, with $s_{y.x}$ of ± 2.72. Moore and Mott (1973) referred to studies by Coward-Lord (1972) with Puerto Rican forages in which true digestibility *in vitro* was predicted from a multiple regression equation including crude protein, CWC and ADF with a multiple correlation of 0.88. In a similar approach with arid, rangeland forages, Smith *et al.* (1971) found that the equation predicting *in vitro* organic matter digestibility with the lowest standard error of estimate ($s_{y.x} \pm 4.75$) involved CWC, acid detergent lignin, silica and ether extract; these variables accounted for 71.7 percent of the total

Table 4
Significance of components in prediction of *in vitro* DDM by stepwise regression procedure

	Number in model	Variables	R^2
All forages	1	ADF	0.38
	2	Lignin, ADF	0.47
	3	CWC, lignin, ADF	0.74
	2	CWC, lignin	0.74
Regression: DDM (%) = 109.5 - 0.53 CWC (%) - 2.41 lignin (%)			$s_{y.x}$ ±2.72
Grasses	1	CWC	0.52
	2	CWC, lignin	0.68
	3	CWC, lignin, lignin/ADF	0.69
	2	CWC, lignin	0.69
Regression: DDM (%) = 114.8 - 0.58 CWC (%) - 2.85 lignin (%)			$s_{y.x}$ ±2.85
Legumes	1	Lignin	0.88
	2	Lignin, tannin	0.92
	3	Lignin, CWC, tannin	0.95
	2	Lignin, tannin	0.92
Regression: DDM (%) = 90.6 - 2.96 lignin (%) - 1.66 tannin (%)			$s_{y.x}$ ±1.90

Variables in the model deemed significant at the 0.1000 significance level.

variance in values for digestibility, with 47.7 percent attributable to CWC. Working with *Pennisetum purpureum,* Johnson *et al.* (1973) noted that CWC and lignin contributed significantly to the prediction of *in vitro* DDM, while crude protein did not.

The multiple regression for prediction of *in vitro* DDM in the population of grasses also showed CWC and lignin as the most significant factors, with a slightly lower R^2 value (0.69). Within the legumes, tannin concentration was found to be a significant factor, although lignin obviously accounted for the greater part (88 percent) of the total variability in *in vitro* DDM.

Conclusions

In general, the results of this study support the conclusions of Moore and Mott (1973) that "there is no clear distinction in quality between tropical and temperate grasses, although tropicals have a lower maximum intake and digestibility." In earlier feeding trials with sheep (Reid *et al.*, 1973), dry matter digestibilities of a number of tropical grasses fed at different stages of maturity ranged from 48.0-74.0 percent, and *in vitro* digestion coefficients of "improved" genera such as *Brachiaria, Chloris, Setaria* and *Panicum* were in the range of 72-80 percent for young, vegetative growth. This was not, however, the case for indigenous grasses such as *Themeda, Hyparrhenia* and

Cymbopogon, in which digestibility was markedly lower. In the present work, analytical results for nitrogen, structural carbohydrates and minerals in tropical grasses and legumes, grown under conditions of adequate moisture and soil nutrients, were quite similar to data reported for temperate forages.

In their review, Moore and Mott (1973) also concluded that "chemical analyses are inadequate as single predictors of tropical grass quality." This might equally be claimed to be the case for temperate forages. However, in view of the very wide range of forages available for selection in tropical areas, and a frequent limitation of animal and laboratory facilities, the development of a simple laboratory measurement with some relevance to feeding value would have considerable merit. In these trials, no single chemical component proved adequate for prediction of digestibility when applied across all forages. Within classes of forage, and particularly with the legumes, there were acceptable correlations between *in vitro* digestibility and either lignin or CWC. Considering ease of determination in the laboratory, use of CWC would suggest itself. Marked improvement in predictive ability was obtained when two or more structural components including lignin were incorporated in a multiple regression equation for the total population of forages. Neither protein nor silica concentration of the forages was found to contribute significantly to the determination of digestibility.

Finally, the appreciable genus, species and varietal differences in structural components, and in their rate of accumulation with increasing maturity, would indicate the usefulness of cell-wall analyses as a selection technique for estimating the potential nutritional quality of tropical forages. The marked differences in mineral accumulation noted, for example, between species of *Brachiaria* and *Setaria,* would form a further basis for selection of grasses and legumes adapted to meet the specific nutritional requirements of ruminant animals.

Acknowledgments

The authors wish to acknowledge the assistance of W. V. Thayne, Associate Professor of Statistics at West Virginia University, for advice in statistical analysis of the data. We also thank the Office of International Programs, West Virginia University, for financial support of the project.

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APPENDIX

Appendix Table 1
Nitrogen concentration, on a dry matter basis, of grasses and legumes harvested at different stages of maturity

Species	Weeks of Growth 1	2	3	4	5	6	7	8	9	10	11	12	14	16	18	20
	Nitrogen (%)															
Grasses																
Andropogon gayanus	2.3	2.4	2.0	2.0	1.7	1.7	1.3	1.1	1.5	1.4		1.1	0.9	0.9		
Beckeropsis uniseta	3.9	3.5	3.0	2.5	2.4	2.4	2.0	2.2	1.8	1.8		1.8	1.4	1.4		
Brachiaria brizantha	3.8	3.4	3.0	2.6	2.4	1.8	2.0	1.5	1.5	1.3		1.2	0.8	0.8		
Brachiaria decumbens		3.1	2.5	2.3	2.3	2.0	2.1	1.6	1.2	1.2	1.0	0.6				
Brachiaria humidicola	3.1	2.9	2.1	2.2	2.3	2.2	1.9	1.9	1.5	1.5		1.2	1.3	1.2		
Brachiaria mutica		4.6	4.2	3.8	3.3		1.7	1.8	2.0	1.1		1.0		0.5		
Brachiaria ruziziensis	3.2	3.3	3.0	2.3	2.4	2.5	2.1	1.5	1.6	1.2		0.9	1.0	1.1		
Cenchrus ciliaris	3.7	3.2	2.6	2.0	1.9	1.6	1.5	1.5	1.5	1.5		1.1	0.8	0.9		
Chloris gayana cv. Masaba	3.8	3.4	3.2	2.5	2.7	2.4	2.1	1.7	1.9	1.5		1.1	1.2	1.3		
Chloris gayana cv. Mbarara	3.9	3.7	3.2	3.0	2.9	2.3	2.2	1.4	1.2	1.2		0.9	0.8	0.6		
Chloris gayana cv. Pokot	3.5	3.3	3.1	2.9	2.7	2.1	1.9	2.3	1.8	1.4		1.4	1.1	1.3		
Cymbopogon afronardus	2.0	1.8	1.8	1.9	1.8	1.9	1.4	1.3	1.4	1.5		1.1	1.2	1.0		
Cymbopogon giganteus	2.1	2.0	1.7	1.8	2.0	1.6	1.6	1.4	1.7	1.7		1.0	1.0	0.9		
Cynodon dactylon		3.2	3.0	3.0	2.6	2.2	2.2	2.1	1.9	1.8		1.7	1.4		1.3	
Dactylis glomerata				3.4		3.2		3.2		3.2				2.4		
Digitaria decumbens		4.2	3.7	3.5	3.3	2.6	2.5	2.0	2.0	2.0		1.9	1.8	1.0		
Digitaria uniglumis	2.0	2.0	2.1	1.9	1.7	1.8	1.6	1.7	1.7	1.7		1.3	1.5	1.0		
Echinochloa pyramidalis	3.2	3.2	2.8	2.4	2.3	2.3	1.9	2.0	1.7	1.7		1.4				
Hyparrhenia cymbaria	3.0	2.8	2.5	2.3	2.2	1.6	1.4	1.5	1.4	1.4		1.0				
Hyparrhenia diplandra	2.2	2.2	2.1	1.8	1.7	1.9	1.3	1.4	1.4	1.4		1.0	0.9	0.7		
Hyparrhenia lintoni	2.1	2.1	1.9	1.7	1.6	1.4	1.3	0.9	1.2	1.0		0.8	1.0	0.8		
Hyparrhenia rufa	2.2	2.3	2.1	1.9	2.2	1.5	1.6	1.7	1.3	1.3		0.9	0.8	0.6		
Melinis minutiflora				3.1	3.0	2.6	2.5	2.1	2.0	1.6	1.4	0.9	0.9	0.9	0.6	
Panicum coloratum	3.8	3.5	2.8	2.8	2.8	2.4	1.9	1.6	1.5	1.4		0.8		1.0		

Species	1	2	3	4	5	6	7	8	9	10	11	12	14	16	18	20
							Nitrogen (%)									
Grasses (cont.)																
Panicum coloratum cv. *makarikariensis*	3.1	2.8	2.8	2.5	2.2	2.3	1.7	1.8	1.3	1.1		0.9	1.0	0.9		
Panicum maximum cv. Creeping Embu		4.0	3.4	2.5	2.4	1.9	1.4	1.5	1.3	1.1	1.1	1.0		0.5		
Panicum maximum cv. Likoni	3.9	3.4	3.4	3.0	2.4	2.2	1.8	1.7	1.4	1.7		1.2	0.8	1.1		
Panicum maximum cv. Makueni	4.3	3.8	2.9	2.3	2.6	2.3	2.1	2.2	2.1	1.7		1.6	1.0	1.2		
Panicum maximum cv. *trichoglume*	4.2	4.2	3.2	3.2	2.9	2.4	1.8	2.0	1.5	1.3		1.1	1.1	1.3		
Panicum repens		2.9	2.6	2.2	2.5	2.5	1.9	2.3	1.9	1.6	1.7	1.3		1.1		
Paspalum commersonii	1.5	1.7	1.6	1.6	1.8	1.8	1.2	1.7	1.3	1.3		1.3	1.1	1.0		
Paspalum urvillei	1.9	2.0	2.2	1.9	1.9	2.0	1.7	1.6	1.9	1.5		1.7	1.4	1.2		
Pennisetum clandestinum	4.0	4.3	4.3	3.6	3.0	2.8	2.4	2.0	2.3	2.5		1.8	1.3	1.0		
Pennisetum purpureum	3.7	3.5	2.9	2.8	3.0		2.3	2.0	1.9	1.9		1.7	1.8	2.0		
Setaria caudula	4.4	3.9	4.1	3.5	3.1	2.4	2.7	2.4	2.1	1.9		1.6	1.4	1.1		
Setaria incrassata	3.1	2.8	2.8	2.5	2.5	2.0	1.9	1.8	1.9	1.3		1.4	0.9	1.0		
Setaria kagerensis	4.9	4.5	3.5	2.6	2.6	1.6	2.1	1.8	1.5	1.3		1.4	1.3	1.0		
Setaria sphacelata	4.1	3.5	3.4	2.7	2.3	1.9	1.1	1.4	1.0	1.0		0.7	0.6	0.5		
Setaria splendida	5.3	4.6	3.8	3.4	3.5	3.0	2.5	2.6	2.4	2.1		1.3	1.4	1.4		
Sorghum sudanense		3.1	2.7	2.6	2.0	1.7	1.4	1.7	1.7	1.2	1.1	1.2		0.5		
Themeda gigantea	2.2	2.1	2.3	1.9	1.8	1.7	1.3	1.6	1.4	1.3		0.9	1.0	1.0		
Themeda triandra			2.1	2.0	2.2	1.9	1.7	1.5	1.5	1.3	1.1	0.8	1.0	0.7		
Legumes																
Centrosema plumieri				4.1	4.3	3.5	3.5	3.8	3.3	2.8	3.2	2.8	3.0	3.2	3.2	
Centrosema pubescens					4.5	4.0	4.1	3.7	2.9	3.1	3.6	3.4	3.6	3.6	3.3	3.4
Desmodium intortum				3.0	3.1	2.4	2.7	2.4	2.1	2.5	2.0	2.1	2.1	2.5	1.9	
Desmodium uncinatum				3.4	3.2	2.7	3.3	3.1	2.5	2.8	3.0	2.7	2.6	2.7	2.2	

Appendix Table 1 (cont.)

Species	Weeks of Growth 1	2	3	4	5	6	7	8	9	10	11	12	14	16	18	20
	Nitrogen (%)															
Legumes (cont.)																
Glycine wightii				3.7	3.7	2.9	3.5	2.9	2.9	2.7	2.9	3.0	3.1	3.0	3.0	
Medicago sativa	4.7	3.8	3.5	2.7	2.9	2.7	2.9	2.9	2.5	2.8		2.4	2.2	2.5		
Phaseolus atropurpureus cv. Siratro						3.9	3.7	3.5	3.5	3.2	3.3	3.3	3.0	3.0	2.9	3.0
Pueraria phaseoloides				3.8	3.6	2.9	3.3	2.7	2.8	2.9	3.0	2.9	2.8	3.1	2.3	
Pueraria javanica				3.6	3.7	3.3	3.2	2.8	2.6	2.7	2.7	3.0	2.6	2.6	2.8	
Stylosanthes gracilis								2.8	2.7	2.8	2.6	2.2	2.4	2.7	2.6	2.3
Trifolium semipilosum				3.7	3.9	3.7	4.0	4.2	3.8	3.5	3.9	3.6	3.3	3.5	2.7	

Appendix Table 2

Cell-wall constituents, on a dry matter basis, of grasses and legumes harvested at different stages of maturity

Species	1	2	3	4	5	6	7	8	9	10	11	12	14	16	18	20
	Weeks of Growth															
	Cell-wall constituents (%)															
Grasses																
Andropogon gayanus	69.1	71.2	72.3	73.0	72.7	76.9	75.7	74.9	73.8	73.9		74.5	76.3	75.0		
Beckeropsis uniseta	51.2	57.2	57.2	62.8	64.4	62.9	63.0	64.4	65.4	66.2		68.8	72.8	73.1		
Brachiaria brizantha	53.8	56.5	63.9	65.4	66.8	66.3	66.2	70.4	71.0	72.1		73.0	73.4			
Brachiaria decumbens		57.4	61.3	65.4	67.3	65.9	66.7	67.3	70.7	75.3	74.0	75.1		75.9		
Brachiaria humidicola	60.6	63.8	67.3	69.8	72.2	69.6	72.5	70.8	76.2	76.9		75.4	75.0	74.6		
Brachiaria mutica		60.6	64.5	72.2	71.3		71.4	70.2	73.8	76.2		79.7		80.4		
Brachiaria ruziziensis	55.3	56.4	58.8	60.3	61.7	61.8	63.6	65.8	65.7	68.1		70.5	70.1	75.6		
Cenchrus ciliaris	53.2	65.3	69.8	72.0	72.5	76.9	76.0	77.1	75.8	80.6		81.3	85.1	85.8		
Chloris gayana cv. Masaba	62.9	67.2	68.3	67.0	69.4	70.8	70.4	76.7	75.3	76.9		76.7	75.3	76.9		
Chloris gayana cv. Mbarara	63.5	65.7	69.2	69.7	71.8	71.6	73.4	77.2	78.4	78.2		79.6	80.4	79.9		
Chloris gayana cv. Pokot	63.9	66.1	70.4	74.3	75.2	72.9	73.6	75.9	75.7	76.5		74.3	74.7	74.4		
Cymbopogon afronardus	70.0	69.1	74.7	74.3	74.8	74.9	75.2	76.3	76.9	79.9		79.8	78.7	79.3		
Cymbopogon giganteus	68.5	70.2	72.3	73.7	75.8	76.2	76.9	75.7	76.4	77.4		76.4	78.1	77.2		
Cynodon dactylon		66.4	65.8	68.4	71.1	71.8	71.0	72.9	74.7	73.4			75.0		74.9	
Dactylis glomerata				55.5		54.3		58.9		62.7					64.1	
Digitaria decumbens		56.0	56.9	55.4	55.7	59.5	60.0	62.7	66.8	64.7		64.3	64.9	64.7		
Digitaria uniglumis	59.1	55.7	61.9	62.2	64.9	67.0	65.0	63.4	65.7	66.1		62.6	64.4	63.9		
Echinochloa pyramidalis	63.8	64.7	64.6	65.8	71.5	71.2	69.3	68.9	72.7	71.9		75.8				
Hyparrhenia cymbaria	64.2	67.9	68.3	69.0	69.9	69.1	69.9	72.1	73.0	73.3		74.6				
Hyparrhenia diplandra	71.7	69.9	73.1	73.4	73.3	74.4	74.9	74.8	74.6	76.6		75.6	76.9	77.7		
Hyparrhenia lintoni	72.6	73.9	72.3	72.3	73.8	75.4	74.7	73.4	75.3	78.2		75.4	76.2	78.8		

Appendix Table 2 (cont.)

Species	Weeks of Growth 1	2	3	4	5	6	7	8	9	10	11	12	14	16	18	20
	Cell-wall constituents (%)															
Grasses (cont.)																
Hyparrhenia rufa	67.4	69.6	69.1	71.2	71.6	73.1	71.9	72.2	73.0	72.6		73.9	75.8	78.5		
Melinis minutiflora				66.9	68.7	69.8	70.7	70.3	72.8	72.1	75.5		78.3		74.5	
Panicum coloratum	58.7	59.3	63.5	61.0	61.0	60.7	63.8	65.4	71.1	71.8		73.6		76.5		
Panicum coloratum cv. *makarikariensis*	72.7	71.8	69.4	73.1	72.8	69.6	71.4	69.3	71.8	73.1		72.9	76.9	74.7		
Panicum maximum cv. Creeping Embu		57.4	61.9	68.5	70.9	73.2	73.3	72.1	75.5	74.6	74.3	76.8		78.8		
Panicum maximum cv. Likoni	63.8	66.1	69.1	67.2	68.4	66.5	72.3	69.1	71.7	72.5		71.5	76.9	75.5		
Panicum maximum cv. Makueni	66.1	66.4		68.8	70.3	70.2	73.1	73.3	74.7	75.9		75.7	76.2	77.9		
Panicum maximum cv. *trichoglume*	60.6	62.7	66.4	65.9	67.2	67.3	69.6	70.7	72.4	73.9		74.7	73.6	77.2		
Panicum repens		65.5	67.4	67.3	68.4	69.5	69.7	67.1	68.1	74.7	71.7	75.1		73.5		
Paspalum commersonii	69.7	70.5	70.3	73.4	71.9	72.4	73.4	72.9	73.7	74.2		73.8	75.9	79.7		
Paspalum urvillei	75.1	76.1	72.2	72.0	70.3	70.8	74.8	74.4	77.0	76.6		75.7	78.6	78.8		
Pennisetum clandestinum	53.9	53.2	56.6	58.4	63.5	63.5	65.8	67.6	68.8	68.7		68.8	73.5	73.0		
Pennisetum purpureum	56.7	60.7	60.8	62.1	63.9		64.8	66.5	68.1	70.6		71.2	73.5	76.7		
Setaria caudula	57.9	58.6	59.9	61.2	62.3	62.7	63.4	67.2	70.5	72.4		70.6	74.1	76.2		
Setaria incrassata	58.7	61.6	63.6	61.7	65.4	67.2	67.2	68.8	68.5	73.1		72.9	73.8	73.4		
Setaria kagerensis	49.2	54.5	55.9	59.3	62.5	64.1	64.7	65.4		66.7		70.3	67.9	68.0		
Setaria sphacelata	52.0	63.6	65.6	67.9	69.2	69.9	72.5	71.4	74.8	77.0		77.9	76.6	81.5		
Setaria splendida	58.8	61.8	68.3	70.7	71.8	72.0	71.8	71.8	73.9	74.1		73.2	75.8	77.9		
Sorghum sudanense		60.6	62.2	62.5	62.1	64.4	66.5	65.9	66.6	69.4	69.0	69.6		77.1		
Themeda gigantea	69.7	75.1	75.8	76.4	76.3	76.7	78.6	77.3	78.7	79.4		78.8	78.4	79.9		
Themeda triandra		74.4	75.8	73.5	75.7	75.0	76.9	77.7	77.3	78.8	79.3	77.6	79.3	80.0		

Species	Weeks of Growth 1	2	3	4	5	6	7	8	9	10	11	12	14	16	18	20
						Cell-wall constituents (%)										
Legumes																
Centrosema plumieri				44.0	44.9	46.7	46.3	50.1	52.8	54.1	55.0	56.5	56.9	57.7		59.1
Centrosema pubescens					44.3	46.6	49.7	53.9	56.8	56.7	58.2	59.0	59.3	60.0		64.0
Desmodium intortum				43.4	42.5	45.8	52.1	52.9		56.5		58.9	59.6	58.3		62.7
Desmodium uncinatum				44.1	44.7	47.6	47.7	52.2	55.6	55.2		58.1	62.4	63.1		65.5
Glycine wightii				40.8	43.9	44.5	45.8	47.9	48.3	50.8	52.2	54.4	55.7	57.3		58.0
Medicago sativa	35.8	40.8	42.1	47.5	50.8	48.6	51.6	52.2	52.7	53.4		56.4	57.3	57.8		
Phaseolus atropurpureus cv. Siratro						43.6		44.4	49.6	50.4	49.8	50.5	52.4	58.0		
Pueraria phaseoloides				35.4	39.4	45.1	44.9	48.3		53.0	54.7	54.3	55.8	55.4		55.3
Pueraria javanica				40.7	46.3	46.6	46.8	52.7		53.9	53.8	55.7	56.2	60.9		59.7
Stylosanthes gracilis								51.5	54.9	54.5		55.7	56.9	57.2		60.3
Trifolium semipilosum				27.7	27.4	29.5	29.5	35.5	40.9	43.2	43.5	44.2	42.9	44.2		48.4

Appendix Table 3

Acid detergent fiber concentration, on a dry matter basis, of grasses and legumes harvested at different stages of maturity

Species	Weeks of Growth 1	2	3	4	5	6	7	8	9	10	11	12	14	16	18	20
	Acid detergent fiber (%)															
Grasses																
Andropogon gayanus	37.5	37.7	39.6	38.7	42.6	42.1	45.7	46.1	40.6	41.7		43.5	49.7	51.0		
Beckeropsis uniseta	28.7	34.4	32.8	34.7	36.9	36.4	35.1	34.3	36.3	35.1		37.7	42.5	43.2		
Brachiaria brizantha	23.9	27.2	31.6	31.8	30.1	33.9	34.8	38.8	41.9	35.2		40.2	40.5	41.0		
Brachiaria decumbens		27.2	29.8	31.0	34.4	36.5	34.8	36.7	38.2	37.9	43.7	40.9	43.0			
Brachiaria humidicola	33.5	36.7	36.6	37.3	36.9	37.5	38.8	36.9	40.3	42.8		41.3	42.9	42.3		
Brachiaria mutica		27.3	27.2	30.0	34.8		39.0	35.6	38.1	46.0		44.3		45.2		
Brachiaria ruziziensis	21.7	25.4	28.7	31.7	33.2	37.0	39.0	38.1	37.3	38.4		40.7	40.9	46.2		
Cenchrus ciliaris	29.5	35.2	37.2	39.0	44.8	44.1	42.7	47.8	44.6	48.9		50.3	55.0	55.4		
Chloris gayana cv. Masaba	30.4	38.3	35.4	36.9	36.6	38.8	42.4	46.7	42.4	43.1		46.2	50.2	48.1		
Chloris gayana cv. Mbarara	31.5	31.8	35.7	35.8	43.1	37.5	41.5	45.3	45.3	48.4		49.4	49.0	52.9		
Chloris gayana cv. Pokot	30.4	35.8	34.5	37.6	38.4	42.4	44.8	40.5	43.0	43.0		44.8	46.9	50.6		
Cymbopogon afronardus	38.6	39.7	42.2	40.6	44.2	40.1	44.1	45.8	41.5	42.4		45.6	46.7	48.0		
Cymbopogon giganteus	37.7	37.8	37.9	38.4	38.0	39.3	40.0	40.0	35.8	38.6		44.3	47.7	45.0		
Cynodon dactylon		31.6	32.7	33.4	33.2	36.6	36.4	37.6	37.2	36.2		38.2	37.5		40.8	
Dactylis glomerata				31.9		31.2		32.1		31.2					37.3	
Digitaria decumbens		29.2	32.8	34.6	31.6	34.8	34.7	41.0	39.2	36.6		35.7	39.2	39.3		
Digitaria uniglumis	35.3	37.8	36.9	40.6	39.3	38.4	39.3	37.4	38.5	38.5		39.9	43.1	45.7		
Echinochloa pyramidalis	31.7	35.9	36.9	35.5	37.9	39.8	37.0	38.5	39.3	39.5		40.7				
Hyparrhenia cymbaria	32.0	33.0	37.8	38.6	41.0	39.1	44.3	42.7	41.0	39.0		45.4				
Hyparrhenia diplandra	39.7	41.6	40.8	44.1	42.5	43.9	42.9	42.7	43.7	45.2		44.8	48.2	49.3		
Hyparrhenia lintoni	42.6	40.9	40.5	40.1	44.6	40.6	47.4	48.4	44.7	46.5		48.4	46.5	50.8		
Hyparrhenia rufa	38.0	41.3	38.2	40.4	41.6	43.6	43.7	43.8	46.0	43.2		48.0	53.0	55.8		

Species	Weeks of Growth 1	2	3	4	5	6	7	8	9	10	11	12	14	16	18	20
	Acid detergent fiber (%)															
Grasses (cont.)																
Melinis minutiflora				35.6	33.0	35.0	37.8	36.7	39.0	44.8	42.7	44.2	48.2	46.7	50.9	
Panicum coloratum	24.6	31.5	31.7	34.4	36.0	39.2	38.9	43.7	42.4	42.8		47.4		50.4		
Panicum coloratum cv. *makarikariensis*	29.8	33.9	31.6	35.5	38.1	43.1	35.0	37.3	37.2	35.6		42.2	39.6	38.3		
Panicum maximum cv. Creeping Embu		32.5	34.4	37.9	39.1	40.3	43.0	43.5	44.4	43.3	46.5	48.9		53.0		
Panicum maximum cv. Likoni	27.1	33.6	35.4	39.1	45.6	45.7	46.1	45.2	46.8	44.1		47.1	53.1	50.1		
Panicum maximum cv. Makueni	27.1	33.2	37.4	38.9	43.1	47.3	49.4	45.3	43.3	46.4		44.9	48.5	52.8		
Panicum maximum cv. *trichoglume*	24.0	31.5	35.5	35.4	40.0	43.9	44.4	46.5	43.5	43.1		44.5	50.3	48.7		
Panicum repens		31.5	31.0	35.7	32.7	33.8	34.8	32.9	34.9	30.3	35.8	36.9		40.7		
Paspalum commersonii	38.9	40.7	41.5	41.3	40.7	36.9	43.5	37.0	43.2	42.9		41.2	39.8	44.6		
Paspalum urvillei	41.0	43.9	41.7	42.3	45.1	41.0	42.6	42.5	43.5	44.3		42.1	47.0	44.0		
Pennisetum clandestinum	24.4	24.6	27.2	30.3	40.2	35.7	34.0	36.6	33.4	35.3		36.4	37.2	39.5		
Pennisetum purpureum	28.5	32.2	32.9	32.8	34.3		39.3	39.6	36.1	37.4		37.3	40.1	40.8		
Setaria caudula	30.7	31.2	34.3	36.1	36.4	38.2	37.2	39.5	39.4	39.1		39.0	45.6	45.4		
Setaria incrassata	37.8	39.7	41.1	42.5	42.5	43.4	41.0	46.5	43.1	46.6		45.1	50.3	48.5		
Setaria kagerensis	25.2	27.6	34.0	36.1	35.1	38.2	36.9	39.3	38.5	40.4		40.3	40.6	42.6		
Setaria sphacelata	24.7	30.9	30.7	32.9	36.8	38.6	42.6	42.5	47.0	46.5		53.7	50.9	54.1		
Setaria splendida	28.3	31.1	31.6	35.3	38.0	39.8	39.9	36.6	37.9	41.4		40.8	41.6	52.8		
Sorghum sudanense		33.8	35.0	37.4	42.3	43.9	41.0	37.1	38.3	42.6	45.6	45.5		52.4		
Themeda gigantea	37.8	43.2	41.0	42.0	42.7	42.5	42.8	42.6	45.0	47.1		48.9	47.2	45.6		
Themeda triandra		42.4	41.7	45.0	42.4	40.9	40.9	41.3	43.9	44.6	45.7	49.6	47.6	48.4		
Legumes																
Centrosema plumieri				31.4	26.7	32.3	34.5	37.2	37.6	39.3	41.3	40.0	37.5	34.9	37.0	
Centrosema pubescens					30.5	32.6	32.8	36.5	40.6	35.5	32.7	36.4	35.6	39.1	42.4	38.0

Appendix Table 3 (cont.)

Species	Weeks of Growth 1	2	3	4	5	6	7	8	9	10	11	12	14	16	18	20
						Acid detergent fiber (%)										
Legumes (cont.)																
Desmodium intortum				29.7	31.7	32.3	33.1	45.0	41.0	35.1		41.1	36.6	36.3	39.6	41.0
Desmodium uncinatum				29.2	32.0	36.3	38.2	46.8	41.7	37.9		37.1	47.7	45.6	45.5	46.1
Glycine wightii				29.2	33.9	37.1	34.2	36.7	36.9	39.1	36.7	36.9	38.2	38.0	39.3	
Medicago sativa	22.1	31.1	34.4	35.7	37.9	38.5	37.1	34.9	38.0	36.7		42.3	43.5	43.1		
Phaseolus atropurpureus cv. Siratro						32.1	33.9	39.0	36.1	36.7	38.8	39.5	37.4	40.2	43.0	42.0
Pueraria phaseoloides				33.5	31.4	34.1	36.5	42.7	37.3	39.1	39.8	40.5	35.5	40.6	42.0	
Pueraria javanica				32.5	33.2	34.6	39.2	43.0	41.4	41.0	42.7	40.9	41.2	42.1	41.4	
Stylosanthes gracilis								34.4	34.4	30.3	35.1	32.2	34.7	38.6	33.8	37.0
Trifolium semipilosum				26.8	22.0	21.8	24.6	28.8	27.3	28.1	25.8	28.4	26.6	29.6	34.9	

Appendix Table 4
Lignin concentration, on a dry matter basis, of grasses and legumes harvested at different stages of maturity

Species	Weeks of Growth 1	2	3	4	5	6	7	8	9	10	11	12	14	16	18	20
	Lignin (%)															
Grasses																
Andropogon gayanus	3.7	4.2	4.5	4.5	4.5	4.5	5.3	5.7	5.3	5.6		6.0	6.7	7.2		
Beckeropsus uniseta	2.9	3.3	3.5	3.7	4.1	5.2	3.9	5.5	4.1	4.2		5.2	5.6	4.5		
Brachiaria brizantha	2.3	3.1	3.8	2.6	2.8	4.1	3.7	5.0	5.5	5.0		5.0	5.6	5.5		
Brachiaria decumbens		2.8	3.2	3.3	3.9	3.1	4.5	4.0	4.6	4.3	5.7	6.1		5.9		
Brachiaria humidicola	3.0	3.2	3.3	4.0	3.0	2.4	5.1	5.1	5.2	5.6		7.2	5.9	5.9		
Brachiaria mutica		3.8	3.7	3.6	3.5		5.8	4.4	4.4	6.9		5.9		7.0		
Brachiaria ruziziensis	2.2	2.8	3.6	3.8	2.7	3.3	3.2	4.0	4.5	4.0		4.8	4.7	5.7		
Cenchrus ciliaris	2.2	3.6	2.6	3.4	4.5	4.4	4.4	6.7	6.4	6.6		7.8	9.3	9.6		
Chloris gayana cv. Masaba	3.8	2.9	3.1	4.3	3.5	4.9	5.5	6.7	5.7	7.7		7.0	7.9	7.2		
Chloris gayana cv. Mbarara	4.1	3.3	3.5	4.2	3.7	3.7	6.1	6.3	6.4	7.0		8.1	8.5	9.6		
Chloris gayana cv. Pokot	2.0	2.6	2.4	4.0	3.9	4.6	4.7	4.6	5.8	4.8		6.8	7.3	8.9		
Cymbopogon afronardus	4.7	5.2	4.6	5.6	5.5	5.9	5.9	7.0	6.9	7.1		8.2	8.0	8.2		
Cymbopogon giganteus	4.5	4.6	4.5	5.4	4.4	5.4	4.6	5.6	5.6	6.0		6.3	7.2	7.5		
Cynodon dactylon		3.9	3.5	4.8	3.7	4.6	5.1	5.8	5.4	5.6		6.6	5.9		8.6	
Dactylis glomerata				5.4		5.8		4.7		4.9					5.8	
Digitaria decumbens		3.0	3.3	5.3	3.5	4.5	3.8	5.5	4.8	5.7		5.2	6.7	6.7		
Digitaria uniglumis	5.0	4.0	4.6	4.8	4.3	4.3	5.0	4.3	4.3	4.8		5.3	6.1	6.9		
Echinochloa pyramidalis	2.7	2.0	2.8	4.0	3.8	3.6	3.9	3.0	3.5	4.8		5.4				
Hyparrhenia cymbaria	3.4	4.0	3.1	4.3	3.8	4.0	5.7	7.1	6.1	6.4		7.2				
Hyparrhenia diplandra	3.5	4.6	3.8	3.9	5.6	4.4	5.2	4.7	4.5	5.9		5.2	6.3	7.3		
Hyparrhenia lintoni	5.8	4.4	4.4	5.1	5.2	4.8	6.3	7.4	6.2	7.2		8.3	8.7	8.7		

Appendix Table 4 (cont.)

Species	1	2	3	4	5	6	7	8	9	10	11	12	14	16	18	20
	Weeks of Growth															
	Lignin (%)															
Grasses (cont.)																
Hyparrhenia rufa	5.0	4.0	4.6	5.0	4.6	5.9	4.7	5.2	5.5	6.1		6.7	8.5	9.0		
Melinis minutiflora				3.4	3.4	3.1	3.5	3.4	4.1	5.4	4.7	7.1	6.0	5.7	8.1	
Panicum coloratum	3.5	4.6	3.9	2.9	3.9	5.3	5.3	6.2	6.3	5.8		7.0		8.0		
Panicum coloratum cv. *makarikariensis*	5.0	3.9	3.6	3.8	5.0	5.9	4.7	4.2	4.7	5.8		6.6	6.5	6.4		
Panicum maximum cv. Creeping Embu		4.0	2.8	4.8	3.4	3.1	4.5	4.7	6.8	5.8	8.5	6.5		10.6		
Panicum maximum cv. Likoni	2.4	3.3	3.8	4.0	5.5	6.4	6.3	7.1	7.2	6.5		6.7	8.1	8.8		
Panicum maximum cv. Makueni	3.5	3.9	4.2	5.0	5.2	6.1	6.3	6.3	5.1	6.4		6.5	6.8	8.1		
Panicum maximum cv. *trichoglume*	3.5	3.7	5.6	4.4	4.9	5.8	6.8	6.7	7.2	7.1		6.7	9.9	8.5		
Panicum repens		4.7	3.1	4.0	5.5	5.3	6.1	4.3	4.2	6.1	3.6	4.9		6.4		
Paspalum commersonii	7.1	6.7	7.5	8.1	7.3	4.8	7.5	6.1	9.0	9.5		8.0	7.5	8.9		
Paspalum urvillei	4.0	3.9	2.9	5.1	4.7	2.8	3.3	4.4	4.3	4.3		4.7	5.3	5.4		
Pennisetum clandestinum	3.7	2.4	2.0	3.5	4.1	5.4	4.1	5.8	5.9	6.2		5.3	4.5	6.3		
Pennisetum purpureum	2.3	3.9	2.2	3.6	3.9		4.3	5.0	4.3	4.7		4.1	5.8	3.5		
Setaria caudula	3.5	1.7	2.0	4.0	3.1	4.3	4.4	5.0	4.4	5.3		5.6	6.3	6.6		
Setaria incrassata	3.0	3.5	2.5	2.0	5.3	5.4	4.1	4.6	4.7	7.5		5.0	5.9	5.7		
Setaria kagerensis	2.9	2.3	3.7	4.1	3.1	4.9	3.5	4.1	4.1	6.9		5.6	3.7	4.7		
Setaria sphacelata	2.3	3.4	2.9	2.5	3.6	2.8	4.7	5.0	6.4	6.3		7.1	7.3	8.5		
Setaria splendida	2.1	2.2	4.3	4.7	3.7	4.2	6.5	4.5	4.2	6.5		7.0	6.7	9.0		
Sorghum sudanense		3.1	3.5	4.4	6.1	5.3	5.0	4.5	5.5	5.5	6.1	7.0		9.8		
Themeda gigantea	2.6	3.3	3.2	3.8	4.3	3.1	4.3	4.7	5.0	6.1		7.4	6.8	6.6		
Themeda triandra		4.9	5.2	5.2	5.1	3.7	4.6	5.7	5.7	7.2	6.7	7.9	7.3	7.7		

Species	1	2	3	4	5	6	7	8	9	10	11	12	14	16	18	20
						Weeks of Growth										
						Lignin (%)										
Legumes																
Centrosema plumieri				7.8	5.8	7.1	7.1	7.7	8.4	8.7	8.7	9.5	8.7	8.4	8.3	
Centrosema pubescens					7.7	7.7	8.4	9.2	9.2	8.1	8.6	10.8	10.1	11.1	11.5	9.6
Desmodium intortum				8.1	7.4	8.1	7.9	14.3	9.1	9.7		10.3	10.9	9.3	11.8	10.5
Desmodium uncinatum				6.7	7.1	8.6	9.6	15.1	10.1	11.0		10.8	15.4	13.9	13.7	14.1
Glycine wightii				6.1	7.1	8.0	6.7	8.3	7.2	8.9	7.9	8.7	8.6	8.8	9.0	
Medicago sativa	4.0	5.4	7.1	7.7	8.4	8.9	8.8	8.5	8.4	8.6		10.2	11.0	10.6		
Phaseolus atropurpureus cv. Siratro						6.6	6.8	7.3	7.4	7.5	7.8	8.0	7.8	8.7	10.0	9.7
Pueraria phaseoloides				8.2	5.8	6.5	7.3	9.7	8.5	9.7	8.5	9.1	7.8	12.1	9.6	
Pueraria javanica				6.0	6.0	6.1	8.2	10.1	8.8	8.9	9.1	9.9	9.1	9.3	8.9	
Stylosanthes gracilis								8.6	11.0	6.3	9.1	6.6	9.4	9.4	7.4	8.4
Trifolium semipilosum				2.7	3.9	2.8	2.8	2.6	4.1	3.2	4.6	3.5	4.6	3.6	5.1	6.1

Appendix Table 5
Mean values for concentration of macro-elements, expressed on a dry matter basis, in forage species harvested over all stages of maturity.

Species	Ca	P	Na	K	Mg
			Percent		
Grasses					
Andropogon gayanus	0.46	0.23	0.03	1.87	0.10
Beckeropsis uniseta	0.86	0.27	0.03	3.50	0.34
Brachiaria brizantha	0.51	0.31	0.04	2.42	0.33
Brachiaria decumbens	0.42	0.29	0.02	2.32	0.21
Brachiaria humidicola	0.19	0.29	0.08	2.21	0.18
Brachiaria mutica	0.38	0.29	0.14	2.75	0.34
Brachiaria ruziziensis	0.61	0.28	0.04	2.21	0.35
Cenchrus ciliaris	0.16	0.25	0.03	3.33	0.10
Chloris gayana cv. Masaba	0.53	0.26	0.07	2.41	0.16
Chloris gayana cv. Mbarara	0.51	0.31	0.04	2.50	0.19
Chloris gayana cv. Pokot	0.52	0.28	0.05	2.88	0.21
Cymbopogon afronardus	0.33	0.24	0.02	2.11	0.13
Cymbopogon giganteus	0.39	0.24	0.03	2.02	0.18
Cynodon dactylon	0.46	0.28	0.04	1.57	0.12
Dactylis glomerata	0.58	0.40	0.08	3.52	0.18
Digitaria decumbens	0.52	0.31	0.09	1.75	0.36
Digitaria uniglumis	0.42	0.25	0.03	2.53	0.15
Echinochloa pyramidalis	0.57	0.24	0.09	3.87	0.36
Hyparrhenia cymbaria	0.68	0.28	0.03	2.33	0.26
Hyparrhenia diplandra	0.40	0.22	0.03	1.70	0.14
Hyparrhenia lintoni	0.44	0.22	0.03	1.50	0.13
Hyparrhenia rufa	0.42	0.23	0.03	1.93	0.16
Melinis minutiflora	0.20	0.29	0.02	2.22	0.21
Panicum coloratum	0.51	0.20	0.06	2.41	0.28
Panicum coloratum cv. *makarikariensis*	0.30	0.22	0.08	2.40	0.13
Panicum maximum cv. Creeping Embu	0.51	0.22	0.04	2.10	0.29
Panicum maximum cv. Likoni	0.44	0.25	0.07	2.19	0.25
Panicum maximum cv. Makueni	0.62	0.26	0.06	2.71	0.30
Panicum maximum cv. *trichoglume*	0.48	0.26	0.10	2.40	0.23
Panicum repens	0.34	0.24	0.08	1.48	0.19
Paspalum commersonii	0.43	0.26	0.03	2.32	0.34
Paspalum urvillei	0.34	0.22	0.03	2.37	0.21
Pennisetum clandestinum	0.37	0.32	0.05	3.56	0.23
Pennisetum purpureum	0.43	0.32	0.03	3.83	0.15
Setaria caudula	0.37	0.24	0.04	2.77	0.20
Setaria incrassata	0.40	0.23	0.03	2.94	0.21
Setaria kagerensis	0.42	0.33	0.03	3.46	0.30
Setaria sphacelata	0.31	0.28	0.04	3.39	0.19
Setaria splendida	0.29	0.23	0.19	2.52	0.20
Sorghum sudanense	0.60	0.26	0.02	1.88	0.27
Themeda gigantea	0.40	0.24	0.03	1.45	0.20
Themeda triandra	0.22	0.24	0.03	1.64	0.16
Mean	0.44	0.26	0.05	2.48	0.22

Appendix Table 5 (cont.)

Species	Ca	P	Na	K	Mg
			Percent		
Legumes					
Centrosema plumieri	1.02	0.38	0.02	2.94	0.48
Centrosema pubescens	1.23	0.38	0.01	2.24	0.27
Desmodium intortum	1.00	0.30	0.01	2.04	0.32
Desmodium uncinatum	0.91	0.38	0.02	2.65	0.23
Glycine wightii	1.40	0.41	0.01	3.18	0.29
Medicago sativa	0.81	0.31	0.04	3.28	0.15
Phaseolus atropurpureus cv. Siratro	1.08	0.32	0.02	2.64	0.37
Pueraria phaseoloides	1.11	0.39	0.01	3.00	0.31
Pueraria javanica	1.17	0.36	0.02	2.62	0.27
Stylosanthes gracilis	1.21	0.38	0.01	2.87	0.22
Trifolium semipilosum	1.16	0.41	0.01	3.41	0.28
Mean	1.10	0.37	0.02	2.82	0.29

Appendix Table 6

Mean values for concentration of micro-elements, expressed on a dry matter basis, in forage species harvested over all stages of maturity.

Species	Cu	Zn	Mn	Mo
		ppm		
Grasses				
Andropogon gayanus	9	33	163	.58
Beckeropsis uniseta	9	33	96	.80
Brachiaria brizantha	9	46	142	1.48
Brachiaria decumbens	9	47	127	1.08
Brachiaria humidicola	9	36	111	.86
Brachiaria mutica	13	45	114	1.20
Brachiaria ruziziensis	9	41	107	1.28
Cenchrus ciliaris	10	26	62	.74
Chloris gayana cv. Masaba	9	32	98	.83
Chloris gayana cv. Mbarara	10	33	95	1.00
Chloris gayana cv. Pokot	10	37	118	1.28
Cymbopogon afronardus	10	57	212	1.26
Cymbopogon giganteus	10	52	237	1.29
Cynodon dactylon	9	37	91	.71
Dactylis glomerata	13	40	495	1.67
Digitaria decumbens	13	53	312	2.28
Digitaria uniglumis	10	38	152	1.33
Echinochloa pyramidalis	13	49	130	1.36
Hyparrhenia cymbaria	10	46	137	1.45
Hyparrhenia diplandra	10	40	221	.78
Hyparrhenia lintoni	9	46	195	.91
Hyparrhenia rufa	8	41	140	1.24
Melinis minutiflora	10	35	78	.85
Panicum coloratum	10	34	102	.92
Panicum coloratum cv. *makarikariensis*	10	34	110	.76
Panicum maximum cv. Creeping Embu	9	33	96	.80
Panicum maximum cv. Likoni	10	36	77	1.19
Panicum maximum cv. Makueni	10	36	126	1.24
Panicum maximum cv. *trichoglume*	11	36	85	1.16
Panicum repens	10	33	119	1.22
Paspalum commersonii	13	31	129	1.96
Paspalum urvillei	11	29	92	1.09
Pennisetum clandestinum	12	40	71	1.20
Pennisetum purpureum	10	33	85	.81
Setaria caudula	11	41	143	1.13
Setaria incrassata	10	38	98	1.52
Setaria kagerensis	10	42	102	1.37
Setaria sphacelata	12	41	123	.69
Setaria splendida	11	46	210	.95
Sorghum sudanense	11	35	94	1.32
Themeda gigantea	11	44	256	1.04
Themeda triandra	8	52	243	1.00
Mean	10	39	143	1.13

Appendix Table 6 (cont.)

Species	Cu	Zn	Mn	Mo
			ppm	
Legumes				
Centrosema plumieri	17	33	124	2.95
Centrosema pubescens	18	36	99	1.26
Desmodium intortum	11	33	132	1.27
Desmodium uncinatum	10	33	96	1.19
Glycine wightii	13	33	59	1.99
Medicago sativa	10	30	40	1.58
Phaseolus atropurpureus cv. Siratro	11	41	82	5.66
Pueraria phaseoloides	15	26	154	1.51
Pueraria javanica	14	37	155	1.19
Stylosanthes gracilis	14	33	74	1.09
Trifolium semipilosum	15	41	73	1.33
Mean	13	34	99	1.91

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