

percentage units in apparent DM digestibility when corn stover with an initial digestibility of 51.6% was treated with 3% ammonia at normal temperature. Snyman *et al.* (1991) thermo-ammoniated non-selected maize residues with an IVDMD of 51.8% under the same conditions as in this trial and found an increase of 7.9 percentage units. Results from Seed *et al.* (1985) showed a difference in DMD of 4.4 percentage units when a diet containing untreated maize residues (DMD = 62.4%) was compared with a diet containing the ammoniated maize residues (DMD = 66.8%). The low response in the present trial might be explained by the initial high digestibility (IVDMD = 56.9%) of the untreated maize residues. (Kernan *et al.*, 1979). Nitrogen intake was higher ($P < 0.05$) on Diet 3 compared to Diets 1 and 2. Faecal N excretion was higher ($P < 0.05$) for ammoniated diets (Diets 2 and 3) compared to Diet 1. This resulted in a lower ($P < 0.05$) apparent N digestibility on Diet 2 compared to Diet 1. An increased faecal-N excretion by animals fed on ammoniated maize residues was also measured by Seed *et al.* (1985) and Snyman *et al.* (1991). Borhami & Johnsen (1981) concluded that a proportion of the ammonia, resulting from ammoniation, was tightly bound to the straw and not released during passage through the alimentary tract. The results of this investigation suggested that the lower apparent CP digestibility of Diet 2 was not merely due to a greater extent of nitrogen unavailability in terms of ADF-N.

It is concluded that the nutritive value of maize residues was improved by thermo-ammoniation. Supplementation of ammoniated residues with fish-meal led to an increased efficiency of utilization. The improvement in DM digestibility due to ammoniation seemed to be influenced by the initial digestibility of the untreated residues. More research is needed to quantitatively relate the effect of ammoniation to the initial IVDMD of maize residues produced under varying conditions. Such data are needed for an economic evaluation of thermo-ammoniation. The eventual economical justification for thermo-ammoniation will depend on the cost of thermo-ammoniated residues compared to alternative roughages with the same feeding value or to the cost of concentrate required to supply the same improvement in nutritive value. During severe droughts when good quality roughage and concentrates are scarce, ammoniation of stored maize residues may also be of strategic importance.

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Prediction of the chemical composition and *in vitro* dry matter digestibility of a number of forages by near infrared reflectance spectroscopy

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The chemical composition and *in vitro* dry matter digestibility of a number of forages, namely lucerne (*Medicago sativa*), Italian rye grass (*Lolium multiflorum*), triticale (*Triticale hexaploide*), oats (*Avena sativa*), tall fescue (*Festuca arundinacea*), babala (*Pennisetum typhoides*), forage sorghum (*Sorghum bicolor sudanense*), weeping lovegrass (*Eragrostis curvula*), Smuts finger (*Digitaria eriantha*) and maize (*Zea mays*) residues, were predicted by a Neotec model 51A near infrared reflectance spectrophotometer. The r^2 values (where r is the simple coefficient of correlation) between laboratory determined and near infrared reflectance spectroscopy (NIRS) predicted values for the different forages ranged between 0.92—0.96 for crude protein (CP), 0.65—0.97 for *in vitro* dry matter digestibility (IVDMD), 0.75—0.95 for acid detergent fibre (ADF) and between 0.34—0.87 for neutral detergent fibre (NDF). Standard errors for NIRS prediction of the chemical components and IVDMD of the different forages ranged between 0.57—1.78% for CP, 1.37—3.82% for IVDMD, 1.11—2.17% for ADF and 1.90—4.47% for NDF.

Die chemiese samestelling en droëmateriaal *in vitro* verteerbaarheid van 'n aantal voergewasse, naamlik lusern (*Medicago sativa*), Italiaanse raaigras (*Lolium multiflorum*), korog (*Triticale hexaploide*), hawer (*Avena sativa*), lang swenkgras (*Festuca arundinacea*), babala (*Pennisetum typhoides*), voersorghum (*Sorghum bicolor sudanense*), oulandsgras (*Eragrostis curvula*), Smutsvinger (*Digitaria eriantha*) en mielie (*Zea mays*)-oestereste is met 'n Neotec model 51A naby-infrarooirefleksiespektrofotometer voorspel. Die r^2 waardes (waar r die enkelvoudige korrelasiekoëffisiënt is) tussen laboratorium-gemete en naby-infrarooirefleksiespektroskopie (NIRS)-voorspelde waardes vir die ruproteïen (RP), droëmateriaal *in vitro* verteerbaarheid (DMIVV), suurbestand vesel (SBV) en neutraalbestande vesel (NBV) vir die verskillende voersoorte het respektiewelik tussen 0.92—0.96, 0.65—0.97, 0.75—0.95 en 0.34—0.87 gevarieer. Die standaardfout vir die NIRS-voorspelling van die verskillende chemiese komponente en DMIVV het gevarieer met 0.57—1.78% vir RP, 1.37—3.82% vir DMIVV, 1.11—2.17% vir SBV en 1.90—4.47% vir NBV.

Keywords: Chemical composition, forage, *in vitro* dry matter digestibility, near infrared reflectance spectroscopy.

Optimal feeding is essential for economical animal production. The most suitable ration for reaching a specific production goal can be formulated only if the exact nutrient quality of the various diet components is known. The forage component may vary greatly in chemical composition and nutritive value, depending on factors such as the kind and amount of fertilizer used, climate, growth stage, etc. (Murray, 1986). Although of great value, the estimation of forage nutrient quality from published tables (NRC, 1988; Allen, 1989; Preston, 1989) is inaccurate and may lead to over- or underfeeding with respect to production needs. Laboratory analysis, on the other hand, is laborious and time consuming so that results often emerge late at the farmer with only retrospective value as management aid. Near infrared reflectance spectroscopy (NIRS), however, is a technique with great potential for a rapid and accurate evaluation of forage nutrient quality (Norris *et al.*, 1976; Shenk *et al.*, 1976). A paucity of NIRS calibrations with respect to the nutrient quality of subtropical forages worldwide, however, exists, while only few calibrations have been developed for South African grown forages in general (Eckard *et al.*, 1988; Stoltz, 1990; Snyman & Joubert, 1992). For most reliable and accurate NIRS prediction of forage nutrient quality, samples used for calibration should be representative of those which

are going to be tested. In this investigation, NIRS calibrations were developed for assessing the nutrient qualities of a number of temperate and subtropical forages grown for ruminant feeding in the Highveld.

Forage samples used for NIRS calibration/validation were: lucerne, Italian rye grass, triticale, oats, tall fescue, babala, forage sorghum, weeping lovegrass, Smuts finger and maize residues. Forages were grown on the experimental farm at Potchefstroom and sampled by hand cutting approximately 3—5 cm above the ground. Samples were taken at various growth stages since the early vegetative to seed stage during 1987 and 1988. The samples were de-activated against enzymatic and microbial degradation by previous heating in a microwave oven (3 min at maximum irradiation) within 15 min after sampling, followed by drying in a force draught oven at 65°C for 48 h. Maize residues were sampled on different farms located in the Highveld Region during the period 1980—1986 and hammermilled through a 6-mm sieve. The dry samples of all forages were ground through a smooth surface 1-mm stainless steel sieve in a Fritsch laboratory cutting mill (pulverisette 15). Nutrient quality of each forage sample was laboratory analysed for crude protein (CP), *in vitro* dry matter digestibility (IVDMD), acid detergent fibre (ADF) and neutral detergent fibre (NDF) as referred to by Snyman (1991). For NIRS prediction of the chemical composition and IVDMD, a Neotec model 51A near infrared reflectance spectrophotometer containing a tilting filter system which allows reading at 768 selectable wavelength points and interfaced with an IBM personal computer, was used. The system was issued with software for NIRS calibration/validation and sample reading developed by Shenk & Westerhaus (1984). Reflectance data were expressed as $\log(1/R)$ (R = reflectance). Samples of the different forages were randomly divided into a calibration sample set (Table 1) for equation development and a prediction sample set (Table 2) for equation validation. Calibration of the instrument was performed by obtaining the NIR spectra for samples in the calibration sample set. Wavelengths at which $\log(1/R)$ fluctuated most with changing values of specific forage qualities (CP, IVDMD, ADF, NDF) were identified by the calibration program by means of multiple linear regression. The wavelengths were incorporated into a prediction equation for each forage quality. The equations were validated by simple linear regression of the laboratory determined vs. the NIRS predicted values of the prediction sample set. Optimum statistics for calibration included a low

Table 1 Mean, SD and range values for the different nutrient qualities of forage species in the calibration sample set

Forage specie	Nutrient quality															
	CP (g/100 g DM)				IVDMD (g/100 g DM)				ADF (g/100 g DM)				NDF (g/100 g DM)			
	n	Mean	SD	Range	n	Mean	SD	Range	n	Mean	SD	Range	n	Mean	SD	Range
Lucerne	80	24.6	5.2	11.9—38.2	78	70.1	5.7	52.2—81.5	78	30.6	6.5	17.1—46.3	79	47.7	6.8	32.7—78.7
Italian rye grass	64	24.5	6.5	9.5—39.4	63	76.4	5.5	56.5—84.6	65	27.4	6.5	15.6—41.4	64	52.0	7.6	35.3—65.9
Triticale + oats + tall fescue	35	24.2	3.9	12.0—31.5	35	78.4	3.7	64.0—85.0	35	26.3	3.9	20.0—38.0	36	45.9	6.8	37.9—69.6
Babala + forage sorghum	92	13.8	4.3	7.2—27.6	93	60.3	9.3	31.8—72.6	92	39.4	4.9	31.4—54.6	78	68.1	3.6	60.2—76.7
Weeping lovegrass	80	11.5	2.9	6.2—19.6	79	53.2	6.3	38.4—71.6	82	42.4	2.7	32.4—47.1	81	84.0	2.9	70.3—92.9
Smuts finger	38	12.2	4.4	4.2—20.5	39	56.5	13.4	35.0—73.2	27	42.6	6.8	32.1—56.4	27	75.8	4.3	67.0—82.4
Maize residues	101	5.9	2.2	2.4—12.9	102	58.3	6.6	40.4—73.8	69	45.1	3.8	36.5—55.7	69	78.4	4.0	68.4—89.6

Table 2 Mean, *SD* and range values for the different nutrient qualities of forage species in the prediction sample set

Forage specie	Nutrient quality															
	CP (g/100 g DM)				IVDMD (g/100 g DM)				ADF (g/100 g DM)				NDF (g/100 g DM)			
	<i>n</i>	Mean	<i>SD</i>	Range	<i>n</i>	Mean	<i>SD</i>	Range	<i>n</i>	Mean	<i>SD</i>	Range	<i>n</i>	Mean	<i>SD</i>	Range
Lucerne	38	23.3	5.3	13.7—34.5	35	69.2	6.6	51.4—79.9	36	31.9	7.2	21.3—56.6	36	48.5	7.1	35.1—67.5
Italian rye grass	33	23.3	7.2	7.8—39.4	32	76.5	6.4	59.2—84.9	31	28.6	6.5	16.5—41.4	30	52.5	7.6	35.3—64.2
Triticale + oats + tall fescue	18	23.8	4.6	14.2—29.4	15	79.2	3.7	70.7—83.0	16	25.6	4.1	21.0—33.3	18	43.3	5.4	36.2—54.2
Babala + forage sorghum	92	13.8	4.4	7.5—24.6	93	60.8	9.2	34.0—74.0	92	39.7	4.9	32.3—52.6	52	68.7	3.3	62.4—76.6
Weeping lovegrass	39	11.6	3.1	6.3—20.1	35	52.6	7.3	39.4—70.2	40	42.6	2.6	36.8—47.7	41	83.9	2.6	75.0—88.2
Smuts finger	20	11.8	4.8	5.1—21.7	19	57.1	12.6	36.0—72.5	13	43.1	6.7	34.0—54.7	13	76.0	4.6	70.1—84.4
Maize residues	97	5.6	2.0	2.0—9.8	96	58.0	6.5	40.0—69.1	66	45.7	3.9	37.2—58.6	68	79.0	4.4	61.9—87.2

Table 3 NIRS calibration statistics and wavelength properties related to equation development for the different nutrient qualities of forage species

Forage specie	Nutrient quality											
	CP			IVDMD			ADF			NDF		
	<i>R</i> ²	SEC ^b (%)	Wavelengths (nm)	<i>R</i> ²	SEC (%)	Wavelengths (nm)	<i>R</i> ²	SEC (%)	Wavelengths (nm)	<i>R</i> ²	SEC (%)	Wavelengths (nm)
Lucerne	0.94	1.32	2220 2360	0.93	1.57	2220 2320 2360 1760	0.91	2.00	2320 2360 1675	0.85	2.62	2360 2220 1676
Italian rye grass	0.93	1.72	2360 2220	0.88	1.87	1760 2360 1636 2100 2360	0.94	1.61	2220 2360 2360	0.78	3.58	2360 2220 1760 2320
Triticale + oats + tall fescue	0.90	1.24	1760 2220	0.83	1.52	1760 1760 2320 2320	0.84	1.54	2100 1760 2360	0.36	5.43	2220 2320 2360 1760
Babala + forage sorghum ^a	0.92	1.24	2220 1658 1760	0.95	2.17	1760 2320 1672 1760	0.91	1.45	2360 1760 2320 1675	0.62	2.24	1760 2100 2360
Weeping lovegrass	0.95	0.66	2320 2220	0.89	2.08	1676 1760 2220 2320 2100	0.73	1.41	2320 1760 2360	0.41	2.20	2100 2360
Smuts finger	0.97	0.79	2220 2220	0.97	2.19	1760 2320 1661 2220	0.94	1.69	1623 2360	0.76	2.12	2360 1678
Maize residues	0.91	0.66	2220 2220	0.74	3.40	1760 2360 2100 1760	0.77	1.85	1760 2360	0.82	1.69	2360 2360 2220 2360

^a *R*² and SEC values for the water soluble carbohydrate content were respectively 0.89 and 1.05 (*n* = 75).

^b Standard error of calibration.

Table 4 NIRS prediction statistics for the different nutrient qualities of forage species

Forage specie	Nutrient quality															
	CP				IVDMD				ADF				NDF			
	SEP(C) ^b				SEP(C)				SEP(C)				SEP(C)			
<i>r</i> ²	(%)	Slope	Bias	<i>r</i> ²	(%)	Slope	Bias	<i>r</i> ²	(%)	Slope	Bias	<i>r</i> ²	(%)	Slope	Bias	
Lucerne	0.94	1.30	1.01	-0.19	0.91	1.97	1.04	-0.08	0.95	1.66	0.97	0.61	0.87	2.61	0.95	0.08
Italian rye grass	0.94	1.78	0.98	-0.32	0.93	1.73	0.91	-0.37	0.94	1.54	1.00	0.01	0.79	3.92	0.94	-0.39
Triticale + oats + tall fescue	0.92	1.36	0.93	0.53	0.90	1.37	1.26	0.37	0.92	1.22	0.90	-0.64	0.50	4.47	0.63	-3.39
Babala + forage sorghum ^a	0.93	1.20	0.99	0.04	0.95	2.04	1.01	0.31	0.90	1.57	1.01	0.05	0.61	2.17	0.75	0.61
Weeping lovegrass	0.95	0.67	0.99	0.16	0.90	2.39	1.08	0.05	0.81	1.11	0.96	0.10	0.34	2.10	0.87	-0.01
Smuts finger	0.96	1.00	1.00	-0.04	0.97	2.44	1.03	0.12	0.91	2.17	0.95	-0.07	0.85	1.90	1.15	-0.20
Maize residues	0.92	0.57	0.93	0.13	0.65	3.82	0.67	-0.07	0.75	1.95	0.85	0.31	0.78	2.08	0.89	-0.16

^a *R*², SEP, slope and bias values for the water soluble carbohydrate content were respectively 0.92, 0.98, 0.95, and -0.09 (*n* = 38).

^b Standard error of prediction, corrected for bias.

standard error (SEC) and a large *R*² value. Optimum statistics for validation included a low standard error of prediction (SEP), a large *r*², a bias value close to zero and a slope value close to 1.0. The calculation of all statistics was performed by the NIRS calibration/validation program (Shenk & Westerhaus, 1984).

The mean, standard deviation (*SD*) and range values for the different nutrient qualities of forages in the calibration and prediction sample sets respectively, are given in Tables 1 and 2. The data indicate that values in the calibration sample set compared well with corresponding values in the prediction sample set. The data also indicate that the nutrient quality values for most forages were largely representative of those that could be expected in practice. Calibration statistics and wavelength properties for equation development are shown in Table 3. Prediction statistics to validate the developed equations are shown in Table 4. The calibration statistics as shown in Table 3 indicate useful calibrations for nutrient qualities of most of the forages. The *R*² and SEC values for the NDF of most forages, however, compared relatively poor with those of the other nutrient qualities. Two wavelength terms were needed for best equation development of CP while mostly more than two were needed for IVDMD, ADF and NDF. This agrees with results of Shenk *et al.* (1979) and Holechek *et al.* (1982). The prediction statistics in Table 4 indicate reliable prediction of nutrient quality for most forages. The *r*² values were generally high (>0.9) while SEP values were relatively low. This is supported by slope values close to 1 and bias values close to zero in most cases. The exceptions, however, were the poor prediction statistics for the NDF content of most forages and the IVDMD of maize residues. The usefulness of applying NIRS in these cases will largely depend on the accuracy that is required. The results in Table 4 furthermore indicate reliable predictions for certain combinations of forages.

In conclusion it can be said that useful NIRS calibrations were developed with respect to the chemical composition and IVDMD of a number of forages most used for ruminant feeding in the Highveld. This will allow quick and reliable prediction of forage nutrient quality, enabling monitoring of the nutrient quality of dietary forage components on a continuous basis.

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