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Pasture Improvement Research in Eastern and Southern Africa

Proceedings of a workshop held in Harare, Zimbabwe, 17–21 September 1984

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Postal Address: Box 8500, Ottawa, Canada K1G 3H9
Head Office: 60 Queen Street, Ottawa, Canada

Kategile, J.A.

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Pasture Improvement Research in Eastern and Southern Africa

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Editor: Jackson A. Kategile

Cosponsored by the
Southern African Development Coordination Committee, Gaborone, Botswana,
and the
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Abstract: The proceedings contains reviews by national scientists on pasture research done primarily in Eastern and Southern Africa (Ethiopia, Kenya, Tanzania, Burundi, Zambia, Zimbabwe, Swaziland, Lesotho, Botswana, Mozambique, and Madagascar). The application of the results obtained and lessons learned are highlighted and used in setting of national priorities for research areas for the future. Critical reviews on current pasture research methodologies are included in the proceedings. The research methods discussed are germ-plasm collection, storage, and dissemination; and germ-plasm introduction and evaluation, nutritive evaluation of pastures, grazing experiments, and range monitoring. Specific guidelines on methodologies are outlined and these are useful to pasture agronomists, animal nutritionists, and range-management scientists.

Two case studies of pasture-research regional networks in Asia and Latin America were presented and discussed. A strategy for future pasture research coordinated through a regional Pastures Network for Eastern and Southern Africa (PANESA) was discussed and agreed upon.

Résumé: Dans les actes ci-joints, des scientifiques de divers pays analysent la recherche entreprise sur les pâturages en Afrique orientale et australe (Éthiopie, Kenya, Tanzanie, Burundi, Zambie, Zimbabwe, Lesotho, Botswana, Mozambique et Madagascar). L'utilisation des résultats obtenus et les connaissances acquises sont mises en lumière, puis utilisées pour établir les priorités nationales en matière de recherche. Les actes comportent une analyse critique des méthodes de recherche actuelles sur les pâturages : rassemblement, entreposage et diffusion du matériel génétique; mise à l'essai et évaluation de ce matériel; expériences de pâturage; évaluation nutritive des pâturages et exploitation rationnelle de ceux-ci. On présente des lignes directrices précises sur les méthodes à suivre, qui seront utilies aux agronomes en charge des pâturages, aux spécialistes de la nutrition animale et aux scientifiques responsables de la gestion des pâturages.

Deux études de cas ont fait l'objet d'une présentation suivie d'une discussion : il s'agit des réseaux régionaux de recherche sur les pâturages en Asie et en Amérique latine. Après discussion, on a convenu d'une stratégie de la recherche sur les pâturages, dans les années à venir; la coordination de cette stratégie sera assurée par une section régionale du Pastures Network for Eastern and Southern Africa (PANESA).

Resumen: En las actas se recogen ponencias presentadas por científicos de diferentes países sobre las investigaciones en pastos que se han realizado principalmente en el Africa oriental y meridional (Etiopía, Kenia, Tanzania, Burundi, Zambia, Zimbabwe, Suazilandia, Lesotho, Botswana, Mozambique y Madagascar). Se destaca la aplicación de los resultados y experiencias obtenidos, muy útiles para determinar las prioridades de las investigaciones futuras en las diferentes naciones. En las actas se recogen también ponencias críticas sobre las metodologías empleadas actualmente en las investigaciones sobre pastos. Se analizan los siguientes métodos de investigación: recogida, almacenamiento, diseminación, introducción y evaluación de germoplasma; evaluación del valor nutricional de los pastos; experimentos de pastoreo; y control de dehesas. Se resumen directrices y metodologías específicas de gran utilidad para agrónomos especializados en pastos, expertos en nutrición animal y científicos especializados en gestión de dehesas.

Se presentan y analizan dos estudios de casos de las redes regionales de investigación en Asia y Latinoamérica. Se discutió y aprobó una estrategia para realizar investigaciones sobre pastos en el futuro que serán coordinadas por la Red de Investigaciones sobre Pastos para Africa Oriental y Meridional (RIPAOM).

CONTENTS

Foreword 7

Participants 9

Keynote Address 15

Session I State of Research Work in Eastern and Southern Africa 23

Pasture Research in Zimbabwe: 1964-84
J.N. Clatworthy 25

Highlights of Pasture Research in Malawi: 1975-84
B.H. Dzowela 59

Pasture Research and Development in Ethiopia
Lulseged Gebrehiwot and Alemu Tadesse 77

Pasture Research in Burundi
Gaboryaheze Astère 92

Survey of Pasture Research in Madagascar
J.H. Rasambainarivo, R. Razafindratsita, and M. Rabehanitriniony 102

Review of Range and Pasture Research in Botswana
D.R. Chandler 115

Review of the Use of Improved Pasture Species in Mozambique
Jonathan Timberlake and António Catalão Dionisio 143

Pastures in Lesotho
C.J. Goebel, B. Motsamai, and V. Ramakhula 153

Pasture Research and Development in Zambia
J. Kulich and E.M. Kaluba 163

Past and Current Trends of Pasture Research in Kenya
Abdullah N. Said 180

Pasture Research in Tanzania
A.B. Lwoga, M.M.S. Lugenja, and A.R. Kajuni 210

Forage Legumes in Agropastoral Production Systems within the Subhumid Zone of Nigeria
M.A. Mohamed Saleem 222

Session II Pasture Research Methodologies and Regional Networks 245

Collection and Preliminary Forage Evaluation of Some Ethiopian Trifolium Species
J. Kahurananga, L. Akundabweni, and S. Jutzi 247

Theory and Practice in Forage Germ-Plasm Collection
J.R. Lazier 260

Germ-Plasm Storage and Dissemination
Adolf Krauss 296

Tropical Pasture Germ-Plasm Evaluation: Strategy and Experimental Designs
A.B. Lwoga 312

Introduction and Evaluation of Large Germ-Plasm Collections 334
D.G. Cameron

Methods of Pasture Establishment
P.J. Grant and J.N. Clatworthy 349

Animal Experiments as a Measurement of Pasture Productivity
P.T. Spear 368

Commercial Seed Increase of New Pasture Cultivars: Organization and Practice
D.S. Loch 392

Evaluation of the Nutritive Value of Forages
Kassu Yilala and Abdullah N. Said 425

Range Monitoring Methodologies
Moses O. Olang 452

Australian-Southeast Asian and Pacific Forage Research Network
T.R. Evans 465

Network Approach in Pasture Research: Tropical American Experience
J.M. Toledo, H.H. Li Pun, and E.A. Pizarro 475

Discussion Summary and Recommendations 499

Research Priorities and Future Strategies on Germ-Plasm Collection (Multiplication, Storage, and Dissemination) 499

Selection and Evaluation Methodologies 502

Establishment and Management 504

Research for Small-Scale/Small Producers Pasture Improvements 506

Organizational Aspects 507

EVALUATION OF THE NUTRITIVE VALUE OF FORAGES

Kassu Yilala and Abdullah N. Said

Department of Animal Production, University of Nairobi, P.O. Box 29053, Nairobi, Kenya

Abstract *Basic biological principles and techniques adopted in the evaluation of the nutritive value of forages are reviewed in two sections. The first presents a discussion on the current concepts of the energy and protein value of forages and examines some of the factors influencing the digestion and metabolism of carbohydrate and nitrogenous components. Attention is drawn to the importance of determining the chemical entities and degradation of OM and N in the rumen. The ME and new protein feeding systems have been noted as they affect new concepts in evaluation systems.*

In the second section, a discussion is presented on some techniques for the evaluation of the energy and protein value of forages. This includes in vivo and in vitro apparent digestibility, in sacco rate of degradation of carbohydrates and protein, in vitro degradation of protein by rumen microbes, and protein solubility and N balance.

As knowledge increased on the understanding of the biological activities operating in the utilization of ingested nutrients by the ruminant animal, the techniques of evaluating the nutritive value of feedstuffs also were modified and refined. Efforts in developing a system of evaluating the nutritive quality of feeds should help predict: (a) the voluntary intake by the animal, (b) the possible end-products of digestion in the rumen and postrumen, and (c) the eventual utilization of the end-products of digestion at the tissue level.

The current state of knowledge recognizes the dynamic interrelationships existing between the chemical nature of the diet, rumen metabolic functions, and tissue metabolism. Various researchers have attempted to develop dynamic simulation models of ruminant digestion (Baldwin et al. 1977; Beever et al. 1980-81) and nutrient utilization (Graham et al. 1976) to help identify the factors influencing the nutritive value of feedstuffs.

In the model by Baldwin et al. (1977) and Black et al. (1980-81), the composition of dietary inputs was described in terms of chemical entities rather than proximate values. Considering the limitations of the proximate system (Van Soest and Robertson 1980; Van Soest 1982) the use of chemical entities in the models is a step forward. The microbes in the host animal do not metabolize proximate or other empirically defined entities as specific dietary components (Baldwin et al. 1977), whereas, compounds such as sugars, starch, pectin, cellulose, etc., can be selectively metabolized and serve as sources of energy, and protein, free amino acids, and nucleic acids, etc. as sources of nitrogen. Plant tissues contain these material entities (Van Soest 1982).

More relevant chemical methods, therefore, to evaluate feedstuffs, which reflect the actual composition, are required to make a relatively accurate prediction of the nutritive value to the animal. Values of chemical analyses need to be combined with biological evaluation comprising voluntary intake, ruminal digestion, and host-animal response.

In this review some aspects of digestion and metabolism of carbohydrate and nitrogenous components will be discussed, together with techniques used to measure degradation of these components in the rumen. Comments are also made on the conventional digestibility and nitrogen balance studies in relation to forages.

RELATION OF CARBOHYDRATE AND PROTEIN DIGESTION AND METABOLISM TO FORAGE EVALUATION

Carbohydrate Components

Various carbohydrate components serve as the major source of energy to the microbes in the rumen.

volatile fatty acids (VFAs), the end-products of fermentation of carbohydrate components, are the main source of metalizable energy (ME) to the host animal. Forage carbohydrates comprise sugars (glucose, sucrose, and fructose), starch, pectin, cellulose, and hemicellulose (Van Soest 1982). The structural carbohydrates, such as cellulose and hemicellulose, ferment slower than starch and soluble carbohydrates like sugars ferment rapidly (Van Soest 1982). The potential extent of digestion of the components could be affected by the content of lignin (Van Soest 1982).

Despite similarities in the overall digestibility of organic matter (OM), differences in gross efficiency of utilization between forages could arise due to differences in sites of digestion of carbohydrates and nitrogen (Ulyatt and MacRae 1974). As shown in Table 1, the differences between Lolium perenne, L. perenne x Lolium multiflorum and Trifolium repens in the apparent digestibility of OM are slight, but the digestibility of OM at different stages in the digestion process is considerably large (Ulyatt and MacRae 1974). These differences have important implications on the utilization of N, and, therefore, on the nutritive value of the species.

From various studies (Beever et al. 1978; Hogan and Weston 1969; Ulyatt and MacRae 1974; Ulyatt and Egan 1979) it has been determined that more than 94% of readily fermentable carbohydrates, about 91% of digestible cellulose, and 85% of digestible hemicellulose (in fresh herbages) appear to be digested before entering the small intestine. Based on this information, and from the data collected on the chemical entities of OM and their apparent digestibilities, it might be possible to estimate the extent of their digestion in various sites and their contribution in energy to microbial synthesis and host animal (Egan 1975). However, the rate and extent of digestion of various carbohydrate components in the rumen can be measured using the synthetic fibre bag technique. This technique is simple, less costly, and provides a rapid and relatively accurate method of measuring the rate and extent of dry matter (DM) degradation (Ørskov et al.1980).

A higher content of soluble carbohydrate is known to result in a more efficient fermentation in the rumen

Table 1. Carbohydrate contents of fresh forages and their digestion when fed to sheep.

Forage	Chemical composition (% DM)[a]				OM[c] (Overall)	Apparent digestibility (%)				In small intestine (% digest.)	Reference
	Readily fermentable carbohydrate		Structural carbohydrate			% In stomach (% digestible)					
	WSC[b]	Pectin	Cellulose	Hemicellulose		WSC	Pectin	Cellulose	Hemicellulose		
L. perenne	8.8	1.4	18.2	11.8	80	- 94 -		90	92	18	Ulyatt and MacRae (1974)
L. perenne x *L. multiflorum*	11.1	1.4	16.9	10.7	81	- 93 -		90	88	30	"
T. repens	9.7	10.3	12.1	3.8	82	- 94 -		91	81	23	"
L. perenne	12.5	1.7	19.0	12.0	84	93	100	92	88	--	Ulyatt and Egan (1979)
L. multiflorum	12.8	1.3	16.6	9.6	87	91	100	88	80	--	"
T. repens	11.6	10.1	13.9	3.9	84	89	96	92	78	--	"
O. viciifolia	9.8	9.8	15.5	5.0	74	90	95	96	91	--	"
L. perenne (spring cut)	19.3	nd[d]	29.4	19.9	74	93	nd	89	87	25	Beever et al. (1978)
L. perenne (autumn cut)	12.4	nd	25.5	19.2	70	92	nd	92	87	35	"

[a] DM = dry matter.
[b] WSC = water soluble carbohydrate.
[c] OM = organic matter.
[d] nd = not determined.

(Beever et al. 1978). With readily fermentable carbohydrates almost completely fermented in the rumen no, or very little, glucose from forages enters or is absorbed from the small intestine (Ulyatt and MacRae 1974). High concentration of readily fermentable carbohydrates (Table 2) in the herbage could result in an increased supply of propionic acid (Tilley et al.1960, Hogan and Weston 1969; Beever et al.1978). Propionic acid serves as a precursor for glucose synthesis (Beever et al. 1978).

It has been noted earlier that the major sources of ME to the host animal are the VFAs absorbed from the rumen. The measurement of ruminal VFA production, with detailed chemical analysis of the forage carbohydrate components, might aid in the assessment of the possible contribution of ME to the host animal (Table 2).

The effects of N fertilization (Hogan and Weston 1969) and maturity of forage (Hogan and Weston 1969; Hogan et al 1969) in lowering the soluble carbohydrate content and reduced ME contribution are shown in Table 2. Low water-soluble carbohydrates result in higher proportions of acetic acid and lower proporations of propionic acid. The efficiency of utilization of acetic acid by the host animal is low, and is dependent on the availability of glucose or glucose precursors (Hovel and Greenhalgh 1978). The effects of molar proportions of propionic acid from various forages on the efficiency of energy utiization is illustrated in Fig. 1.

Based on the points mentioned earlier it is desirable to examine the chemical composition of forages in terms of the carbohydrate entities rather than the proximate crude fibre (CF) and nitrogen free extractives (NFE). The combination of these with data made available on the rate and extent of digestion of the entities in the rumen could assist in the identification of the possible reasons for the differences between species in nutritive value. Coefficients of overall apparent digestibility could be misleading as measures of nutritive value (Ulyatt and MacRae 1974; Beever et al.1978) under certain conditions.

Table 2. Concentration of water soluble carbohydrate (WSC) in fresh forages fed to sheep, proportion of volatile fatty acids (VFAs) in the rumen, and estimated quantities of metabolizable energy (ME) (Kcal) available from the VFAs.

Forage	WSC	Molar % of total VFA			ME contribution (Kcal)/100 g OM intake				Reference
		Acetic	Propionic	Butyric	Acetic	Propionic	Butyric	Total	
	(% DM)								
White clover	6.0	65	21	14	-	-	-		Tilley et al. (1960)
Perennial rye grass	7.9	63	22	15	-	-	-		
Cocksfoot	10.2	61	25	14	-	-	-		
Timothy/meadow fescue	12.9	58	26	16	-	-	-		
Lucerne	7.8	58	26	16	-	-	-		
	(% OM)								
P. tuberosa									
Early forage	20.9	66	20	11	89	58	40	187	Hogan et al. (1969)
Mid season	15.1	68	20	10	58	38	35	131	
Late forage	11.3	71	18	10	79	46	30	155	
Oats									
Maturity I									
Unfertilized	16.0	59	26	16	87	55	42	184	Mogan and Weston (1969)
Fertilized	5.0	67	21	12	99	46	32	177	
Maturity II									
Unfertilized	18.0	61	21	18	82	41	32	155	Mogan and Weston (1969)
Fertilized	8.4	64	23	13	86	45	42	173	
Maturity III									
Fertilized	5.8	67	19	14	79	33	28	140	

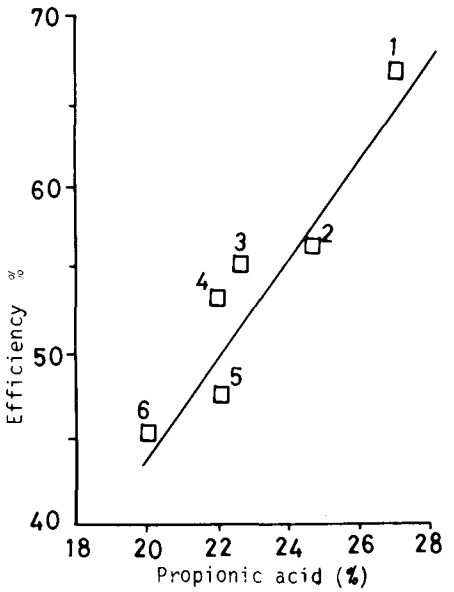

Fig. 1. The relationship between efficiency of energy utilization for growth and molar proportion of propionic acid on six pastures: 1 = ryegrass + clover, 2 = tall fescue + clover, 3 = ryegrass, 4 = tall fescue, 5 = cocksfoot + clover, 6 = cocksfoot (Grimes et al. 1968)

Relation of Nitrogenous Components of Forages to Evaluation Studies

The evaluation of the protein value of tropical grasses and legumes has to follow the current understanding of the process of N digestion in the rumen, because such processes have a considerable influence on the fate of dietary proteins. Despite the adequate amount of N, the productivity of animals from tropical grasses was found to be low, and this was believed to be due to the limitations in the contents of digestible energy (DE) (Royal and Jeffrey 1972). However, the results of Stobbs et al. (1977) showed that cows fed Chloris gayana containing 20% CP with a solubility of 40% and supplemented with formaldehyde-treated casein produced 20% more milk than from the unsupplemented diet (Table 3). Flores et al. (1979) also demonstrated that cows grazing young fertilized C. gayana increased their milk production when supplemented with 2 kg/day of fresh Leucaena leucocephala, the protein of which was less soluble than that of C. gayana. Based on the concentration of NH_3-N in the rumen, Stobbs et al

Table 3. Mean yield and composition of milk of cows fed on C. gayana supplemented with untreated or formaldehyde (HCHO) treated casein or L. leucocephala.

Diet	Milk yield (kg/cow/day)	Butter fat yield (g/day)	Protein yield (g/day)	Reference
C. gayana[a]	12.3	630	410	Stobbs et al. 1977
C. gayana + casein	12.7	660	420	
C. gayana + HCHO-casein	14.7	710	520	
% response to:				
Casein	3.3	4.8	2.4	
HCHO-casein	19.5	12.7	26.8	
C. gayana[b]	9.6	470	356	Flores et al. (1979)
C. gayana + HCHO-casein	10.1	504	385	
C. gayana + Leucaena[c] (2 kg)	10.3	502	374	
C. gayana + Leucaena (4 kg)	10.3	503	374	

[a] Composition: TN (% DM) = 3.1, Protein solubility = 40, OM digestibility = 68
[b] Composition: TN (% DM) = 2.4, N solubility = 32, D value = 62, Soluble CHO = 5.3
[c] Composition: TN (% DM) = 3.7, N solubility = 21, D value = 63, Soluble CHO = 11.9

(1977) estimated the effective protein content of C. gayana diet to be about 13% rather than the chemically determined 20%.

The incubation of Panicum maximum, L. leucocephala, and Desmodium intortum (Aii and Stobbs 1980), and Stylosanthes humilis (Playne et al. 1972) in synthetic fibre bags suspended in the rumen showed considerable differences in the disappearance of N (Fig. 2). Miller (1980) reported the disappearance of N from field beans (Vicia faba) to be lower than that of lucerne when incubated in the rumen. From this he concluded that the protein value of field bean, despite its contents of amino acids, was only comparable to urea.

Dietary N concentrations are the most widely used terms in describing the protein value of forages. Considering the differing solubility and degradation rates of N in the rumen of different plant proteins it could be misleading to use total N concentration as a measure of the protein value of forages. Solubility and degradability of protein could be used as the basis of classifying forage proteins (Hennessy 1980). The results of Aii and Stobbs (1980) demonstrated the

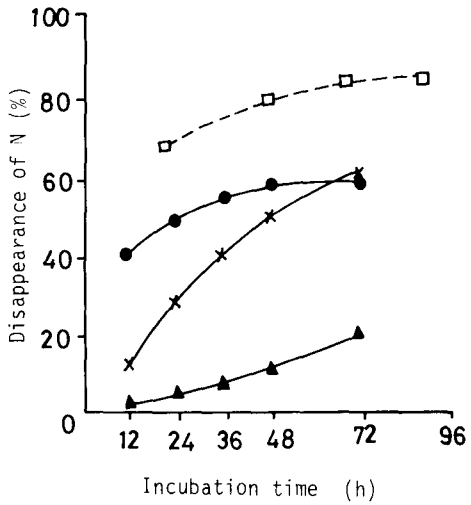

Fig. 2. Disappearance of N from synthetic fibre bags suspended in the rumen. ● = P. maximum, x = L. leucocephala, ▲ = D. intortum (Aii and Stobbs 1980); and □ = S. humilis (Playne et al. 1972)

existence of a wide variation in protein solubility between species and between different parts of the plant (Table 4).

In fresh young herbage, the DM fraction is high in N content, which is mainly in a soluble form and, therefore, is rapidly available to the rumen fermentation (Ulyatt and MacRae 1974). The degradation of high N diets could result in the production of excess NH_3, with the large proportion of it being absorbed through the rumen wall, converted to urea in the liver, and lost in the urine (Ulyatt and MacRae 1974; Klooster et al. 1977; Miller 1980). The graphs in Fig. 3 and values in Table 5 (Catton et al. 1982) illustrate the mismatching of OM supply and requirement for the efficient capture of degraded N by rumen microbes. Although the discrepancy between the requirement and the OM supplied is considerably larger for the "badly" fermented, the utilization of degraded N could be inefficient in both

Table 4. Protein solubility (%) of various plant parts in herbages (Aii and Stobbs 1980).

Forage	Cutting stage	Leaf	Stem
Grasses:			
C. gayana	Bloom	29.7	48.2
P. clandestinum	Prebloom	24.0	66.4
S. anceps	Prebloom	20.0	29.0
D. decumbens	Bloom	24.4	22.7
P. coloratum	Bloom	33.4	39.3
P. maximum	Prebloom	25.7	33.5
B. mutica	Bloom	33.5	53.0
Legumes:			
M. atropurpureum	Immature	40.8	52.9
D. intortum	Immature	7.6	15.9
D. uncinatum	Immature	5.3	36.3
A. indica	Immature	21.0	48.5
M. uniflorum	Immature	44.7	54.5

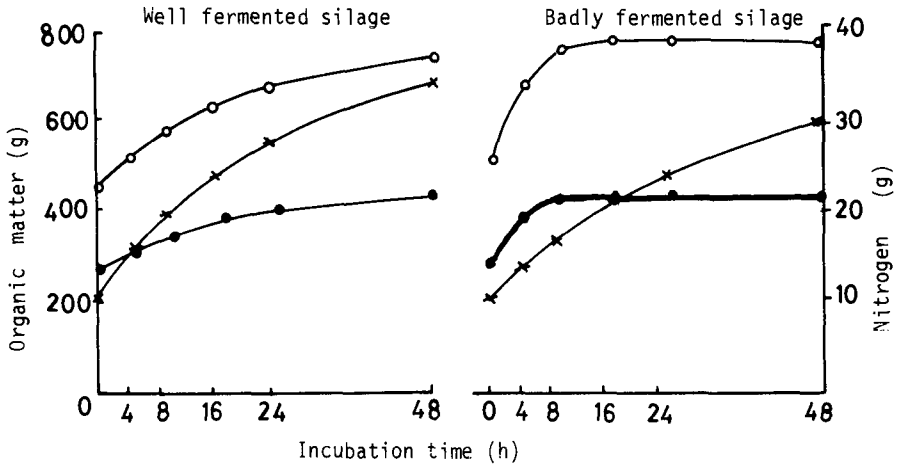

Fig. 3. Losses of nitrogen (N) and organic matter (OM) from bags over 48 hours and calculated OM requirement for each kilogram of silage DM, o = N loss, x = OM loss ● = OM requirement (Catton et al. 1982).

Table 5. Losses of nitrogen (N) and organic matter (OM) from bags and calculated carbohydrate requirement to match OM and N losses in early stages of degradation (up to 4 hours) (Catton et al. 1982).

	Type of silage	
	"Well" fermented	"Badly" fermented
Potential degradability (%)		
N	86	88
OM	76	67
Pattern of release within the first 4 hours of incubation		
N (%)	67	90
N (g/kg silage dry matter (DM)	15	20
Calculated CHO requirement to match OM and N losses during the first 4 hours of incubation (g)	239	394

silages. The synchronization of N degradation and OM release in the rumen is of paramount importance for the efficient capture of NH_3 by the microbes (Meggison et al. 1979). Illustration of the theoretical scheme of the required energy and N synchronization in the rumen is presented in Fig. 4. The effects of availability of readily fermentable carbohydrate on N utilization is shown in Table 6.

The points mentioned so far, therefore, suggest that degradability of protein in the rumen should be considered for the evaluation of the protein value of forages. To determine the degradability of forage proteins in the rumen, the dual requirements of the animal must be recognized for rumen degradable nitrogen (RDN) for microbial cell growth and the dietary N reaching the small intestine to meet tissue needs (ARC 1980; Miller 1980). Furthermore, it allows the manipulation of protein supply and minimizes the losses that could occur as a result of excessive supply of N (Fig. 5).

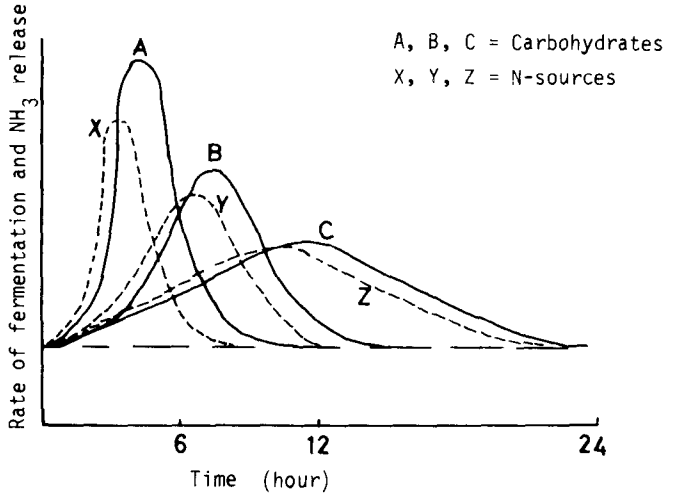

Fig. 4. Illustration of the theoretical rumen fermentation rates over time after ingestion of three forms of feed carbohydrates. (A = soluble sugars, B = starch, and C = cell wall components, and rumen NH_3 curves (-----) required to support protein synthesis from fermentation of these carbohydrates (Johnson 1976).

Table 6. Chemical composition of fresh forages fed to sheep and N intake, digestion, and utilization.[a]

Forage	Chemical composition: Readily fermentable carbohydrate WSC (% DM)	Pectin (% DM)	TN (% DM)	Soluble-N (% TN)	N intake (g/day)	App. digestibility of N (%)	NH_3 in rumen mg N/100 mL	N in urine (g/day)	N retained (g/day)	Reference
L. perenne	8.8	1.4	4.2	37	38	85	-	27.2	4.8	Ulyatt and MacRae 1974
L. perenne x L. multiflorum	11.0	1.4	3.8	38	35	81	-	20.6	7.6	
T. repens	9.7	10.3	3.9	50	35	82	-	24.8	3.9	
L. perenne	12.5	1.7	3.8	-	31	84	-	24.3	2.0	Egan and Ulyatt 1980
L. multiflorum	12.8	1.3	3.9	-	35	86	-	27.9	1.8	
T. repens	11.6	10.1	4.0	-	34	84	-	26.0	2.1	
O. viciifolia	9.6	9.8	3.4	-	34	74	-	20.8	4.7	
Oats:										
Maturity I										
Unfertilized	17.0	-	3.6	12.7	31	77	16	19.2	5.7	Hogan and Weston 1969
Fertilized	5.0	-	5.0	22.3	40	78	33	28.8	1.9	
Maturity II										
Unfertilized	18.0	-	1.9	12.1	14	66	11	6.6	3.2	
Fertilized	8.4	-	3.5	21.0	28	78	20	13.0	3.9	
Maturity III										
Fertilized	4.8	-	1.3	18.4	6.0	55	5	3.1	0.3	

[a]N = nitrogen, WSC = water soluble carbohydrate, DM = dry matter, TN = total N.

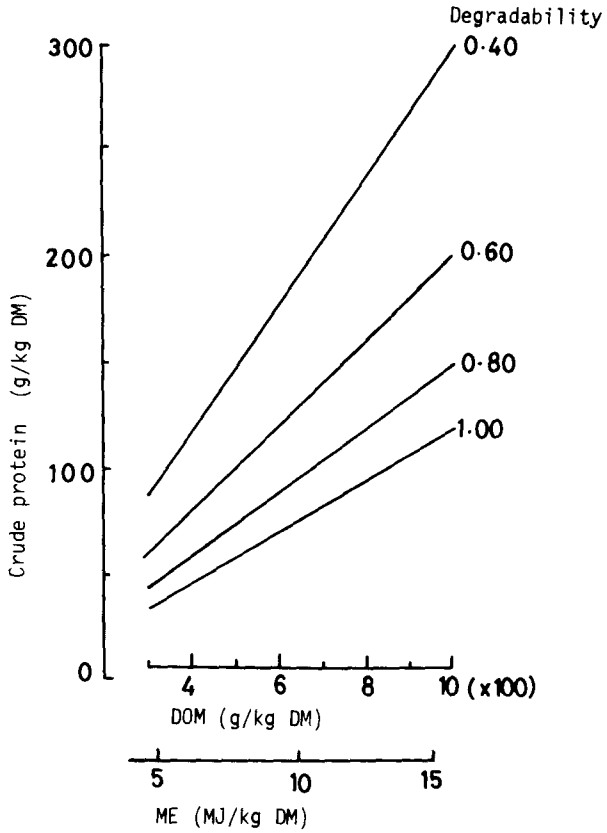

Fig. 5. Crude protein required for rumen microbes with diets differing in digestibility and protein degradability (ARC 1980).

In general, the division of N inputs into RDN and UDN (undergraded dietary nitrogen) is a simple, logical, and useful approach to supply N to the ruminant animal. Therefore, assessing the protein value of forages in terms of their degradability in the rumen instead of the traditional digestible crude protein (DCP) appears to be necessary. DCP indicates the overall disappearance of N between feed and faeces only (Klooster al al. 1977; Miller 1980). It does not indicate that dietary proteins are largely degraded in the rumen and that microbial production is related to the amount of carbohydrate fermented in the rumen (Klooster et al. 1977). In the DCP system, the excess NH_3 absorbed from the rumen is regarded as apparently digested N, and, yet, has no value to the tissue needs of the host animal (Klooster et al. 1977). Also, with DCP, it is not

possible to relate the N requirements of the animal to the energy intake and concentration of energy in the feedstuffs to formulate diets (ARC 1980).

With the new protein system, however, (e.g., ARC 1980) the use of RDN and UDN estimated at a given energy input and concentration of energy in the feedstuffs is used to formulate diets (Fig. 5), i.e., once the ME requirement for maintenance and production is known then it is possible to estimate the amount of N needed for microbial synthesis (RDN) and tissue needs (microbial protein + UDN) using the following equations (see ARC 1980): (1) RDN = 1.25 ME; (2) TMN = 0.53 ME, where TMN is the tissue N supplied by microbial N; and (3) UDN = 1.91 TN - 1.00 ME, where TN is total tissue N required.

The energy value of forages could be expressed in terms of ME from digestibility data (see the section on "Apparent Digestiblity"). The use of the ME system could be a suitable basis for feed evaluation in the tropics (Van Es 1980).

Because the requirements of N and sulphur (S) to the microbes are interdependent, the estimated RDN requirement can be used to calculate for S requirements (ARC 1980): (4) S = 0.07 RDN. It is well established that S is essential for microbial synthesis and its deficiency could result in a depressed rate of digestion in the rumen (ARC 1980).

PROCEDURES FOR EVALUATING FORAGES

The preceding sections bring out the importance of a more elaborative and schematic approach in the evaluation techniques for pastures beyond the conventional systems. In this section the following schemes of pasture evaluation will be considered: chemical analyses, apparent digestibility (in vivo and in vitro), rate and extent of degradation of carbohydrates and N in the rumen (in sacco), in vitro degradation of protein, solubility of protein, and N balance.

The advantages and weaknesses of most of these techniques have been discussed by Pidgen et al. (1980) and will not be repeated here.

Chemical Analyses

Most of the data available on the chemical composition of tropical forages are of a proximate system. Based on the discussions in the previous sections, the following chemical entities should be determined: water soluble carbohydrates, starch (Smith et al. 1964), cellulose, hemicellulose, acid detergent fibre (ADF), neutral detergent fibre (NDF), lignin, lipids, ash, total N (AOAC 1975), residual-N (Batty 1972), and sulphur (Wimberley 1968).

Apparent Digestibility

The evaluation of the energy value of feedstuffs is based on the measurements of digestibility either in vivo or in vitro.

In Vivo Digestibility

Despite the amount of physical work involved and the amount of time and money required, this technique is widely used. The estimation of energy from in vivo digestibility is more reliable than it is from any other laboratory estimates (Heaney 1980).

Organic matter (OM) digestibility can be expressed as digestible energy (DE) or digestible organic matter in the dry matter (DOMD or D). The mean energy value of the digestible organic matter (DOM) in tropical forages is similar to that found in temperate forages and the following equation can be used to calculate ME (Minson 1980): (5) ME = 0.81 DE.

The expression of the energy value of tropical forages in terms of ME will allow the adoption of the new energy and protein feeding systems in the tropics. This will demand the availability of in vivo-measured ME values of forages that could serve as standards (Minson 1980).

In Vitro Digestibility

For tropical pasture species the most accurate laboratory technique to predict in vivo digestibility is the in vitro method (Minson et al. 1976). Chemical methods such as ADF and lignin predict digestibility with higher errors (Minson et al. 1976) because of the

variation in the proportion of the apparent DOM arising from cell walls (Osbourn and Terry 1977).

The D-value determined from this approach can be used to estimate ME as in Equation 6 (MAFF 1975), provided the technique has been calibrated against estimates of digestibility in vivo (Moe 1980): (6) ME = 0.15 DOMD.

In Sacco Degradability in the Rumen

The synthetic fibre bags can be used in measuring the in vivo rate and extent of degradability of forage dry matter components in the rumen. In this technique (Ørskov et al.1980), the test feed is placed in synthetic fibre bags and suspended in the rumen. The pores of the bag chosen (36 μm) are meant to allow the easy passage of rumen fluid and bacteria while retaining the insoluble dietary fraction. After incubating for a given length of time the bags are removed, washed, dried, and the residue chemically analyzed for the components, such as DM, N (Ørskov et al. 1980), and carbohydrate fractions (Catton et al. 1982). The technique gives characteristic disappearance curves from which the rate and extent of disappearance of the components can be calculated using the equation (Ørskov et al. 1980): (7) $P = a + b\ (1 - C^{-ct})$ where P = the amount degraded at time (t); a = the rapidly soluble fraction, i.e., intercept; b = the amount that will degrade in time; and c = the fractorial rate constant at which the fraction described by b will be degraded per hour.

The way in which the forages are prepared for the test may need to reflect the material that is fed, because certain treatments like drying could influence the degradability of protein (Ørksov 1982). Dry forages could be ground through a 2.5 mm screen, whereas fresh forage samples need to be minced through a 5.5 mm screen (Ørskov and Mehrez 1977) or cut to a size that will allow an adequate amount of homogenous sample (Filmer 1982). Care must be taken not to lose the juice while cutting or mincing. Because of the high moisture content of fresh forages the amount of sample in the bag should be at least 12 g, and dry forages should be 5 g (Filmer 1982).

Although the accuracy of the technique is influenced by certain factors, its simplicity and low cost

(once the animal has been acquired and fistulated) and the information it provides on the degradability of the materials in the rumen will improve the evaluation of the nutritive value of forages (Ørskov et al. 1980). The usefullness of the technique for the evaluation of forages can be seen from the illustrations in Figs. 2 and 3. The rate measurements will allow the assessment of the synchronization of energy release and N degradation in the rumen.

Ayres et al. (1976) ran ruminal digestion with synthetic fibre bags concurrently with conventional in vivo digestion and found a close association between the two. The synthetic fibre-bag technique offers potential for the evaluation of forages under field conditions (Ayres et al. 1976). There is, however, an urgent need to standardize the technique, particularly the size and porosity of bags, number of bags in the rumen, form of the test material, level and type of basal diet fed to the animal, incubation time, and animal replications (Said et al. 1984).

Solubility of Protein

Although solubility is not synonymous with degradation of protein (Miller 1982), the method is an improvement in predicting the protein value of forages (Aii and Stobbs 1980).

The technique involves (Crooker et al. 1978) the mixing of ground (1 mm screen) test material containing 50 mg N and 200 mL of solvent, preheating to 40 °C with the pH adjusted to 6.5 using orthophosphoric acid (85%) in an extraction flask. After incubating for 1 hour at 40 °C with constant stirring the feed-solvent suspension is filtered. The amount of extracted N in a 50 mL aliquot of the filtrate is determined and the soluble N expressed as a proportion of total N in the feedstuff.

Sodium chloride or autoclaved rumen fluid could serve as solvents to the test (Crooker et al. 1978). Furthermore, a specific mineral mixture was used by Aii and Stobbs (1980). However, considering the shelf life and similarity of results between the various solvents (Crooker et al. 1978), sodium chloride could be

preferred. For further comments on the technique refer to Verite (1980).

In Vitro Degradation of Protein by Rumen Microbes

The in vitro techniques used to estimate the degradation of protein in the rumen have generally been based on the accumulation of NH_3 released from the protein when incubated in rumen liquor (Broderick 1978; Spears et al. 1980). The technique (Spears et al. 1980) of measuring the in vitro NH_3-N accumulation involves the incubation of the feed sample in 250 mL Erlenmeyer flasks fitted with bunsen valves at 39 °C. Each flask contains 1 g of substrate and 100 mL of a 1:1 mixture of rumen fluid and synthetic rumen saliva. The quantity of NH_3-N in each flask is measured at various stages of incubation. The flasks are flushed with CO_2 initially and at each time of sampling to maintain anaerobic conditions.

The technique is not without limitations (Broderick 1978): (a) the uptake of NH_3 for microbial growth can reduce estimates of degradation particularly with feeds high in readily fermentable carbohydrates unless an inhibitor of end-product metabolism (e.g., hydrazine sulphate) is used, and (b) simple accumulation of NH_3 does not take into account the rate of ruminal passage of the protein, which has a considerable influence on the escape of protein from the rumen. The technique, however, is simple and its perfection might satisfy the need for laboratory batch tests to evaluate the degradability of proteins by microbes in the rumen.

Nitrogen Balance

Nitrogen balance studies, based on faeces and urine collection in metabolism cages, have been used widely to evaluate the protein value of feedstuffs. Because of the discrepancies in the techniques the data are used only as relative comparisons rather than absolute values (Asplund 1979). However, the measurement of retained N by the host animal supported with measurements of rates of disappearance of N and OM, concentration of NH_3 and proportions of VFAs in the rumen could enable a better interpretation of the results and, therefore, provide and improvement in the evaluation of the protein value of forages under a given condition.

Variation in N balance may be associated with voluntary intake if the animals are fed ad libitum (Asplund 1979), the balance data will reflect the state of the animal rather than the characteristics of the feed. Therefore, feeding at less than the required level is recommended to evaluate the availability of N for retention (Asplund 1979). Previous nutrition has a profound influence on the magnitude of N retention (Asplund 1979; Hovel et al. 1983; Yilala and Bryant 1984) during the test period. The adaptation diet should, therefore, be at the maintenance level (Asplund 1979).

CONCLUSION

Protein nutrition is the major limiting factor to utilize the abundant forage structural carbohydrates energy by ruminant animals in the tropics. Both the quantities and quality of N are important. Some of the findings on N availability to rumen microbes do indicate that a number of tropical forages, particularly legumes, have their proteins in protected form. The efficient use of such legumes as supplements to low-protein basal diets demands the knowledge of their chemical entities and biodegradability in the rumen. The metabolism of protein is not independent of energy metabolism. The efficient utilization of high N tropical grasses, at early stages of growth, does require the availability and release of energy at the rate that will match the rate of N degradation in the rumen. Also, in the tissues, protein synthesis is dependent on the availability of energy from high-energy phosphate molecules.

The values currently recommended to "satisfy" the nutrient needs of ruminants reflect a better understanding of the digestive and metabolic processes in the rumen and at tissue level than it was in the past. This refinement in the knowledge of the biological processes cannot be seen in isolation from the development in the techniques of measurements. In the review, attempts have been made to demonstrate the need to describe the nutritive value of tropical forages in accordance with some aspects of the current state of knowledge in ruminant nutrition, i.e., the adoption of new techniques and modifications of the conventional approaches,

depending on the objective conditions, are necessary to fit into the new feeding system.

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