ASSESSMENT OF THE QUALITY OF FORAGE FROM ITS CHEMICAL COMPOSITION AND APPLICATION TO FEEDING PROGRAM

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ABSTRACT

Development of a forage testing method is necessary as a first step to design a feed program for cow. For this purpose, nutritive value of forages was evaluated by chemical and enzymatic methods in this experiment.

Temperate grasses such as orchard grass, Timothy and grass-legume mixed forage were prepared to hay and were fed to sheep in 19 digestibility experiments. In addition, six tropical grasses including Bahia grass, Rhodes grass, finger millet, fall panicum, Makarikari grass, and green panic were cut at the first, second and third growth.

Three analytical methods were applied to all samples. The methods consisted of proximate analysis, detergent analysis and enzymatic analysis.

In the enzymatic system, feed organic matter (OM) was divided into two fractions, organic cellular content (OCC) and organic cell wall (OCW) using amylase and protease. Isolated cell walls were subjected separately to cellulase digestion; thus OCW was divided into two fractions, organic a (Oa) which was hydrolysed rapidly by cellulase, and organic b (Ob) which was resistant to cellulase digestion. Therefore OM was expressed as follows: OM=OCC+Oa+Ob.

The following results were obained.

1 *In vivo* digestibility of OCC was higher than that of OCW in hays prepared from temperate forages. *In vivo* digestibility of Oa of hays averaged 93.9%, whereas the average digestibility of Ob was 42.0%.

2 Estimation of forage total digestible nutrients (TDN) from the relationship between crude fiber contents and TDN gave a large value of standard error (5.2%). However multiple regression equation including the contents of OCC plus Oa and Ob gave better results (r=0.93, Se=2.4%). Regression equation by enzymatic analysis was as follows:
TDN=1.111 (OCC+Oa)+0.605 Ob−18.8.

3 This equation was applied to TDN estimation of 18 tropical grass samples. Mean TDN value of second cutting grasses grown in high temperature summer season was 57% and this value was lower than that of the first cutting (61%).

4 Lignin and silica contents of tropical grasses were generally higher than those of temperate grasses.

Introduction

Traditionally the measurement of the nutritive value of feed is carried out by *in vivo* digestion tests, with obvious limitations when the comparison of a large number of feeds is required. Accordingly more rapid and simple techniques have been sought for estimating the nutritive value using laboratory analyses. Such procedures include the proximate analysis, *in vitro* digestion procedures and detergent analysis (Von Soest, 1967).

Recently the author has developed an enzymatic method of analysis for feed evaluation (Abe and Horii, 1979; Abe and Nakui, 1979; Abe *et al.*, 1979). This report describes the methods for estimating the total digestible nutrients of forages and their application to tropical grass samples.

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Calculation of total digestible nutrients (TDN)

Evaluation of ruminant feed invariably requires the assessment of digestibility of the various fractions. For determining the utilizable energy of feeds, net energy (NE) and a metabolizable energy (ME) system are used in the United States and England. In Japan, TDN system is applied to feeding standards for cattle. The value of TDN depends on the digestibilities of the feed fractions obtained by proximate analysis and calculation is as follows:

TDN =digestible crude protein (DCP)+2.25×digestible ether extracts (DEE)+digestible crude fiber (DCF)+digestible nitrogen free extracts (NFE) ··························(1)

The equation for digestible organic matter (DOM) can be written as follows :

DOM=DCP+DEE+DCF+DNFE ··························(2)

The next equation is obtained by referring to equation (2) (Itoh, 1967)

TDN=DOM+1.25×DEE··························(3)

For the calculation of TDN, it is necessary to determine the contents and digestibilities of crude protein, crude fat, crude fiber and NFE. However it is possible to calculate TDN based on two components of organic matter and ether extracts by using equation (3). Digestible dry matter (DDM) which is a suitable index of the nutritive value of forages is represented by equation (4):

DDM=DOM+digestible ash (D−ash) ··························(4)

Equation (3) can be transformed as follows:

TDN=DDM−D−ash+1.25×DEE ··························(5)

Table 1 shows a comparison between DDM, DOM, and TDN values and the contents of D-ash and 1.25×DEE. Since in corn silage, the value of 1.25×DEE was higher than that of D-ash, therefore TDN had a higher value than DDM (see Table 4). However in other forages, the reverse tendency was observed. Generally, the contents of EE of hays range from 2-4% and their digestibilities range from 40 to 60%. As a consequence the value of 1.25×DEE never exceeds 4% in ordinary hay. As shown in Table 1, the differences in the values of TDN and DOM between grass and legume were smaller than those of TDN and DDM values.

Figure 1 shows the relationship between DOM and TDN of grass hay, grass-legume mixed hay (Table 8) and alfalfa hay. There was a highly significant correlation ($P<0.01$) between these values.

Proximate analysis and prediction equation of TDN

For a long time, TDN content of forage has been estimated by regression equations from one or two components based on proximate analysis (Adams *et al.*, 1964; Meyer and

Table 1 Contents of DDM, DOM, TDN, digestible ash (D-ash) and 1.25 x digestible ether extracts (DEE) of hays and silages

% DM

Feed	DDM	DOM	TDN	D-ash	1.25 DEE
Alfalfa	56.4	52.5	53.4	3.9	0.9
Orchard grass hay	64.0	57.5	59.4	6.5	1.9
Corn silage	66.5	64.8	68.2	1.7	3.4
Rice straw	39.3	37.3	38.0	2.0	0.7
Rhodes grass silage	56.7	52.4	54.4	4.3	2.0

Values obtained by digestion trials using sheep or goat.

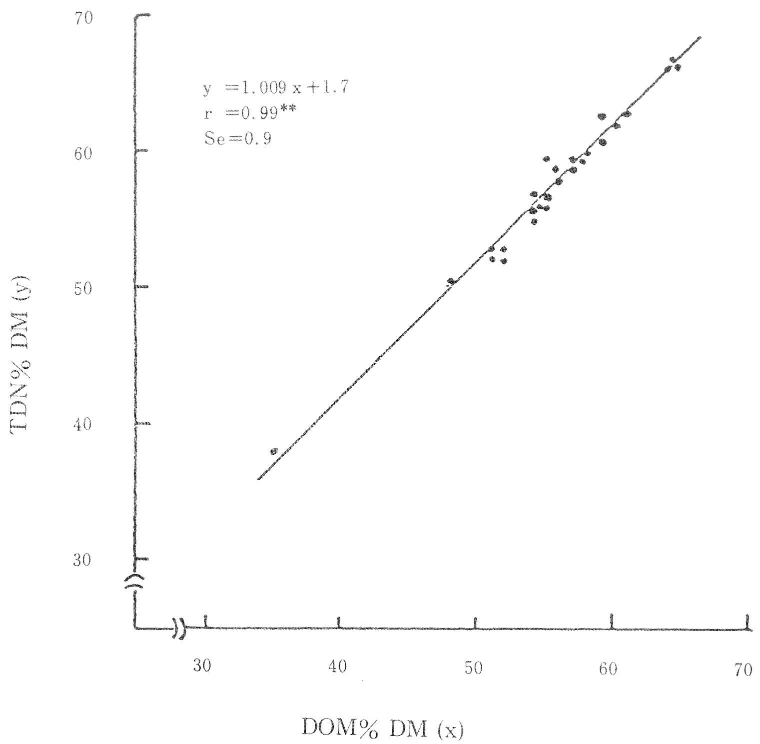

Fig. 1 Relationship between digestible organic matter (DOM) and TDN of hay (Table 8).
**P<0.01

Lofgreen, 1959; Naga and El-Shazly, 1971) (Table 2). In proximate analysis of feed, carbohydrates which are the main components of TDN are expressed in tems of crude fiber and NFE. However there is a significant disadvantage from the view point of chemical and nutritional levels (Van Soest, 1966), because fibrous materials such as structural carbohydrates and lignin are distributed in fractions of both crude fiber and NFE. Table 3 shows the composition of NFE in various feeds. NFE includes the highly available carbohydrates (non-structural carbohydrates such as sugars, starch and fructosan) and low digestible fibers.

Contents of the fiber fraction in NFE of grass hay exceeded 50%.

Table 4 shows the digestibility of NFE, crude fiber, fiber fraction in NFE and non-structural carbohydrates. The original concept of NFE was centered on the characterization of the highly digestible carbohydrates in feed, while crude fiber was assumed to represent the indigestible part of feed. However crude fiber was sometimes more digestible than NFE as shown in Table 4. The low digestibility of NFE resulted partially from the extraction of the fiber fraction in the course of the determination (Table 3).

Detergent analysis and summative method for DDM

Attempts have been made to substitute the use of crude fiber and NFE for other methods such as the analytical system developed by Van Soest (Van Soest, 1967).

Figure 2 shows the distribution of forage organic matter determined by the detergent system. Proteins, sugars, starch and lipids of the plant cell in category A (cellular contents, CC) are generally available to ruminants. However components in category B (cell wall, CW)

Table 2 Regression equations for predicting TDN from proximate analysis

Forage	Regression equation
Legume	TDN=74.43+0.35CP−0.73CF
Grass	TDN=50.41+1.04CP−0.07CF
Corn silage	TDN=77.97−0.75CP−0.07CF
Alfalfa	TDN=78.7−0.803CF
Legumes	TDN=57.70+0.72EE
Non-legumes	TDN=0.623(100+1.25EE)−0.1179CP
Straws	TDN=0.503(100+1.25EE)−0.4960CP

CP : Crude protein, CF : Crude fiber, EE : Ether extracts.

Table 3 Composition of nitrogen free extracts (NFE)

% DM

Feed	NFE	Composition of NFE		
		NSC	Fiber	Other solubles
Timothy	45.3	10.4	31.4(69)	3.5
Orchard grass hay	30.9	4.0	24.9(81)	2.0
Alfalfa hay cube	38.4	4.2	16.8(44)	17.4
Corn silage	56.4	31.4	23.6(42)	1.4
Mixed feed	57.1	35.7	20.6(36)	0.8
Formula feed	61.7	42.3	13.9(23)	5.5
Beet pulp	63.2	8.5	46.3(73)	8.4

( ) : Percent of fiber fraction in NFE, NSC : Non structural carbohydrates, sugars, starch, fructosan and lactic acid; Mixed feed : rice straw, 37 % and formula feed, 63 %.

Table 4 Digestibilities of nitrogen free extracts (NFE), crude fiber, fiber fraction in NFE and non structural carbohydrates (NSC) of various feed samples

%

Feed	NFE	Crude fiber	Fiber fraction in NFE	NSC
Timothy hay	68.7±1.7	72.1±0.8	64.7±1.3	95.9±0.2
Orchard grass hay	56.3±1.3	70.7±2.0	50.9±2.2	96.3±1.5
Alfalfa hay cube	67.0±1.1	40.7±1.4	38.3±2.7	93.8±1.1
Corn silage	74.2±0.9	63.4±1.9	48.8±2.2	99.4±0.1
Mixed feed	71.8±1.1	44.5±3.4	30.1±3.4	98.9±0.3
Formula feed	90.5±0.7	47.7±16.9	61.3±5.7	99.5±0.2
Beet pulp	87.5±2.7	82.9±1.8	88.2±1.5	94.9±1.3

Mean ±SD. (4-6 animals, sheep or goat) ; Mixed feed : Rice straw 37 % and formula feed 63 %.

Fraction	Components	Nutritional availability	
		Ruminant	Non-ruminant
	Category A		
Cell contents (soluble in neutral detergent)	Lipids Sugars, organic acids, and water soluble matter Starch Nonprotein nitrogen Soluble protein Pectin	Virtually complete	Highly available
	Category B		
Cell-wall constituents (fiber insoluble in neutral detergent)	Attached protein	Complete	High
Soluble in acid detergent	Hemicellulose	Partial	Very low
Insoluble in acid detergent (acid-detergent fiber)	Cellulose	Partial	Very low
	Lignin	Indigestible	Indigestible
	Lignified nitrogen compounds	Indigestible	Indigestible
	Heat-damaged protein	Indigestible	Indigestible
	Keratin	Indigestible	Indigestible
	Silica	Indigestible	Indigestible

Fig. 2 Classification of forage organic matter by system of analysis, using detergents.
Source : Van Soest, 1966.

show a low availability.

DDM can be written as follows in the system of detergent analysis.

DDM = digestible CC (DCC) + digestible CW (DCW) ……………………………………(6)

A useful approach to the prediction of the nutritive value of forage is the Lucas test. In the Lucas test, the amount of digestible components to be tested (digestibility coefficient × forage content) is expressed in terms of the percentage of the components in the dry matter or forage (Van Soest, 1967). The regression constant is an estimate of the endogenous excretion of the component, while the regression slope is an estimate of the average true digestibility. Level of correlation and standard deviation of the regression coefficients are estimates of the nutritional uniformity of chemical components (Van Soest, 1967).

Figure 3 indicates the relationships between digestible CC and CC content in dry matter. The regression slope shows a low standard deviation (Table 5) and a high value of the correlation coefficient ($r=0.99$, $P<0.01$) was obtained. An average true digestibility of 98% and endogenous excretion of 12.9% can be applied to estimate DCC in equation (6). However Figure 4 and Table 5 show that the fraction of CW was not uniform in the nutritional level.

In the estimation of CW digestibility, Van Soest recommended to express the lignin values as the percentage of cell wall components.

When ratios of lignin to acid detergent fiber (ADF) are correlated with digestibilities of CW, very high values can be obtained (Table 5), and the following equation was derived.

CW digestibility = 147.3 − 78.9 log lignin/ADF

Therefore, equation (6) can be written as follows :

DDM = (0.980CC-12.9) + CW (147.3 − 78.9 log lignin/ADF) ································(7)

Furthermore, in grasses silica is an important component affecting digestibility, and there is a decrease of 3.0%of DDM per 1%silica. Table 7 shows an example of calculation of DDM by applying the summative method for green panic. To simplify the estimation of CW digestibility, Table 6 illustrates a conversion table for CW digestibility based on the content of lignin and ADF (USDA).

Enzymatic analysis and TDN estimation

Van Soest used a neutral detergent (sodium lauryl sulfate) for the fractionation of feed organic matter to CC and CW, whereas the author investigated the possibility of utilizing various enzymes for the same purpose (Abe and Horii, 1979; Abe and Nakui, 1979; Abe *et al*., 1979). Figure 5 shows the scheme of enzymatic analysis.

Organic matter (OM) of feed is divided into two fractions, organic cellular contents (OCC) and organic cell wall (OCW), using amylase and pronase (Actinase) or pronase alone. Isolated cell walls were subjected separately to cellulase digestion, thus OCW was divided into two fractions : organic a (Oa) and organic b (Ob). Therefore OM was expressed as follows : OM = OCC + Oa + Ob.

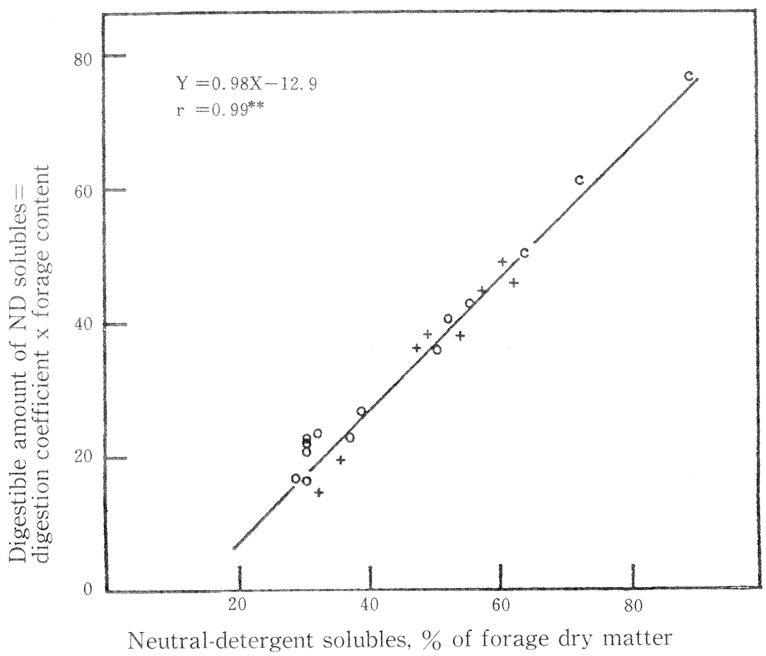

Fig. 3 Relationships between the digestible amounts of cellular contents and total amounts in dry matter, measured as dry matter soluble in neutral detergent (ND). Grasses denoted by ( ) ; legumes (+) and concentrates (c).

Source: Van Soest, 1967.

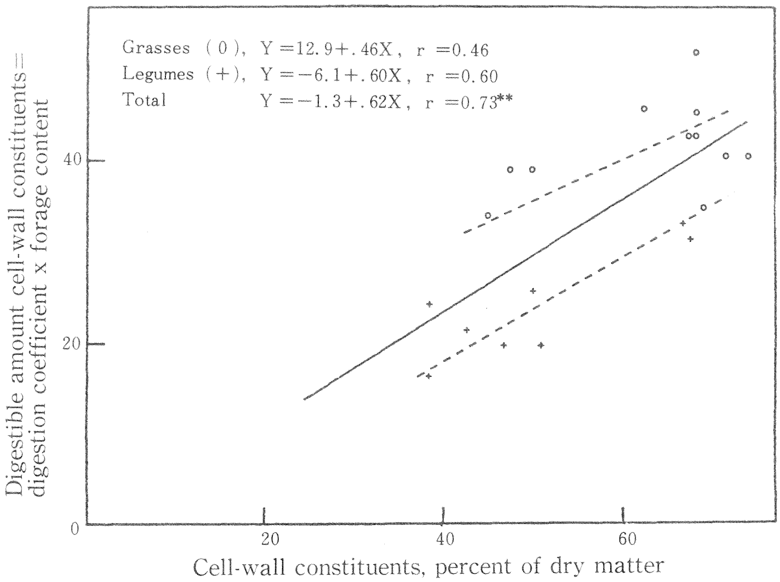

Fig. 4 Relationship between the digestible amount of cell walls and the total content in dry matter.
Source: Van Soest, 1967.

Table 5 Correlations of digestible amount with forage content, estimates of average true digestibility and correlations of apparent digestibility with indices of lignification for different forage fractions (Van Soest, 1967)

Fraction	Correlation of digestible amount with content	Estimated true digestibility[b]	Correlations of apparent digestibility with		
			Lignin/ cell wall	Lignin/ ADF[c]	Log lignin ADF[c]
		%			
N×6.25	0.99**	93± 3.1	−.14	−.16	−.21
Cellular contents	0.99**	98± 2.5	−.14	−.15	−.21
Cellulose	0.67**	50±13.5	−.83**	−.91**	−.93**
Hemicellulose	0.94**	79± 6.7	−.85**	−.86**	−.90**
Holocellulose	0.83**	73±11.7	−.87**	−.93**	−.96**
Acid-detergent fiber (ADF)	0.50*	30±12.6	−.86**	−.93**	−.95**
Cell wall	0.73**	62±14.1	−.90**	−.95**	−.98**

b : Slope of the regression of digestible amount in the relation to forage content.
c : Acid-detergent fiber.

*P<0.01, **P<0.01

Table 6 Conversion of lignin/ADF ratios to estimated cell wall digestibility

Lignin/ADF 100	Estimated CW digestibility %
4	90
6	85
7	81
8	76
9	72
10	68
11	65
12	62
13	59
14	57
15	55
16	52
17	50
18	48
19	46
21	43
23	40
25	37
27	34
30	30
35	25
40	21
45	17
50	13

Lignin : Determined by 72 % sulfuric acid.
Source : Goering and Van Soest, 1970.

Table 7 Example of calculation of DDM by summative method based on detergent analysis for green panic

% DM

Component	Contents	Factor	Digestible amounts
Cellular contents	37.4	×0.98	+36.7
Cell wall	62.6		
Lignin	3.8		
ADF	33.5		
Lignification of ADF	11.3		
Cell wall digestibility		×0.65	+40.7
Silica correction		×3.0	−13.5
Estimated true DDM			63.9
Metabolic fecal matter			−12.9
Estimated DDM			51.0

Detailed analytical method is as follows. A ground sample (0.5g) was heated with 20 ml of water in 100 ml Erlenmeyer flask to gelatinize starch. After cooling, 20 ml of 0.005%(W/V) alpha amylase solution (pH 5.8) were added, the mixture was incubated at 40°C for 16 hr with continuous shaking to hydrolyze starch. and then filtered through filter paper. Residue was subjected to digestion by 0.02%(W/V) pronase in phosphate buffer (pH 7.4). The residue was washed in a 50ml polystyrene tube with approximately 45 ml of pronase solution from a polyethylene wash bottle, the suspension was incubated with continuous shaking for 16 hr at 40°C, and was filtered through a filter paper. Residues were washed with water and acetone, dried in a forced air oven at 105°C for 4 hr, and weighed after cooling in a desiccator. The residual OM was obtained by subtracting its ash content, and this fraction was designated as organic cell wall (OCW). The fraction of OM digested by amylase and pronase was referred to as organic cellular contents (OCC), and expressed as OM minus OCW.

When a sample did not contain starch as in the case of grass, amylase treatment was omitted.

Analytical method for Oa and Ob determination is as follows. Samples corresponding to 0.3 g of CW were treated with amylase-pronase or pronase alone in the same manner as described in the OCW determination. Residue on the filter paper after pronase digestion, that is CW, was transferred into a 50 ml polystyrene tube with approximately 45 ml of 1.0%(W/V) cellulase solution, acetate buffer pH 4.0, from a polyethylene wash bottle.

Cellulase hydrolysis was performed at 40°C for 4 hr. Residual OM was measured by the same method as that for the determination of OCW, and this fraction was designated as organic b (Ob). The fraction of OCW digested by cellulase hydrolysis was termed organic a (Oa), and was expressed as OCW minus Ob.

Table 8 shows the origin of the grass and mixed hay materials used in this experiment and Table 9 shows the chemical composition of these hays. The contents of ADF and crude

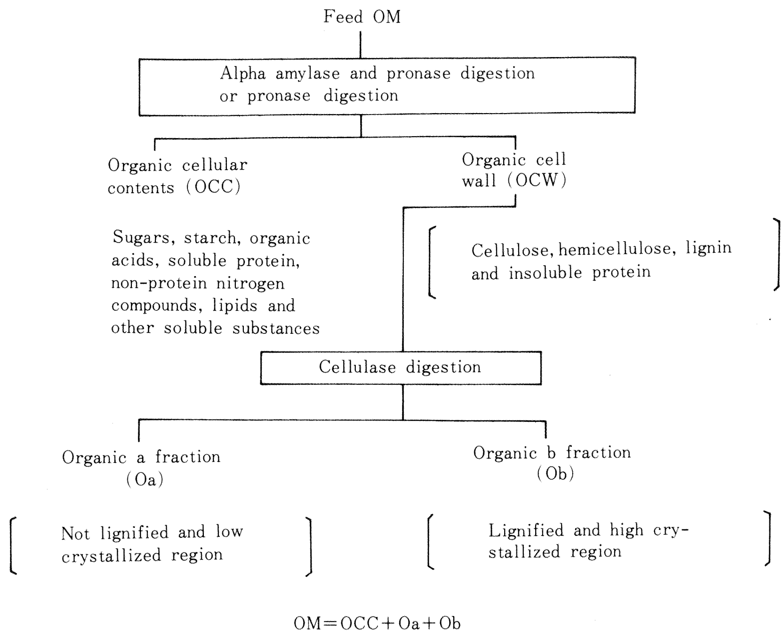

Fig. 5 Separation of feed organic matter (OM) constituents by enzymatic analysis.

fiber are also listed in this Table.

Table 10 shows the TDN contents and digestibility of various fractions obtained by enzymatic analysis of hays. Digestibility of OCW was not uniform and OCW could be divided into two fractions with high and low digestibility respectively.

It is worth noting that the digestibility of Oa was particularly high. Digestibility of Oa averaged 93.9%,whereas the average digestibility of Ob was 42.0%. It thus appears that the digestibility of OCW is strongly influenced by the ratio of Oa and Ob in OCW.

Hydrolysis of plant CW by cellulase is a reaction operating on heterogenous substrate. Thus the reaction proceeds rapidly initially and then becomes slower (Abe and Horii, 1974). Cell wall structural carbohydrates which are dissolved rapidly by cellulase may be the portion which is less lignified and of low crystallinity. Oa consists mainly of cell wall materials that are hydrolyzed rapidly.

Figures 6 and 7 show the relationships between the contents and digestible amounts of OCC+Oa and Ob. Correlations were high ($P<0.01$) in both cases. Therefore it can be considered that OCC+Oa and Ob have a uniform nutritive level. In the enzymatic system, DOM can be written as follows, based on the results from Figures 6 and 7.

$$\begin{aligned} \text{DOM} &= \text{digestible (OCC+Oa)} + \text{digestible Ob} \\ &= 1.002\ (\text{OCC+Oa}) + 0.551\ \text{Ob} - 13.8 \end{aligned}$$

OCC consists of sugars, starch, protein, lipids and other soluble substances and this fraction shows a high or complete availability.

Based on the data listed above, it is considered that fraction Oa has properties similar to those of OCC. Therefore it appears that high availability and nutritional uniformity can be extended beyond OCC to OCC+Oa.

From the regression equation shown in Figure 6, it is estimated that values for metabolic fecal OM and true digestibility of OCC+Oa are 8.3%and approximately 100%, respectively.

Table 11 shows the regression equation and correlation coefficients for estimating TDN

Table 8 Data on grass and mixed hay used in this experiment

No.	Kinds of forage, cutting schedule and growth stage
Grass or mixed hay	
1	Orchard grass, first growth, vegetative stage
2	Orchard grass, first growth, early heading
3	Orchard grass, first growth, flowering
4	Orchard grass, second growth, vegetative stage
5	Ten days after cutting of No 4
6	Orchard grass, third growth, vegetative stage
7	Rice straw
8	Mixed hay consisting predominantly of orchard grass, first growth, heading
9	Second growth of No 8, vegetative stage
10	Mixed hay, first growth of timothy (heading) and red clover (flowering)
11	Two weeks after cutting of No 10
12	Orchard grass, second growth, vegetative stage
13	Timothy, first growth, flowering
14	Orchard grass, first growth, late heading
15	Orchard grass, first growth, heading
16	Mixed hay, first growth of orchard grass (heading) and red clover (flowering)
17	Mixed hay, second g owth of timothy, ladino clover and alfalfa
18	Timothy, first growth, late heading
19	Mixed hay, first growth of orchard grass (heading) and red clover (flowering)

Table 9 Chemical composition of grass or mixed hay

% DM

Forage No.	Organic matter (OM)	OM		OCW		Crude protein	Crude fat	Crude fiber	Acid-detergent fiber
		OCC	OCW	Oa	Ob				
1	89.6	42.4	47.2	24.8	22.4	16.5	5.3	23.5	26.6
2	89.9	33.7	56.2	24.7	31.5	12.3	4.3	29.7	33.0
3	88.8	23.5	65.3	16.0	49.3	8.0	4.3	33.6	39.3
4	85.7	28.7	57.0	21.9	35.1	15.5	6.2	30.3	34.3
5	85.8	28.0	57.8	22.1	35.7	14.1	6.1	30.1	34.7
6	88.4	33.7	54.7	20.5	34.2	22.2	6.3	28.0	32.3
7	80.2	11.4	68.8	9.4	59.4	5.5	4.0	34.5	41.4
8	94.6	28.3	66.3	18.9	47.4	13.9	3.3	32.4	38.3
9	93.7	28.3	65.4	16.8	48.6	17.1	4.3	32.0	39.0
10	89.8	32.2	57.6	21.4	36.5	—	3.9	27.7	32.4
11	90.4	27.6	62.8	13.1	49.7	—	2.3	30.6	36.0
12	87.3	27.7	59.6	13.2	46.4	12.7	3.4	31.2	37.1
13	92.3	18.3	74.0	19.0	55.0	8.9	2.0	36.6	43.3
14	89.5	24.0	65.5	17.2	48.3	8.8	3.0	32.4	37.6
15	88.9	20.2	68.7	20.1	48.6	11.6	2.4	34.5	39.0
16	90.6	34.9	55.7	13.1	42.6	13.8	2.9	27.8	36.9
17	92.6	29.8	62.8	13.1	49.7	12.3	2.9	30.6	38.8
18	93.7	20.8	72.9	13.7	59.2	6.9	2.3	36.3	43.4
19	93.4	33.6	59.8	20.3	39.5	12.9	3.4	28.7	33.6

OCC : Organic cellular contents, OCW : Organic cell wall,
Oa : Organic a fraction in OCW, Ob : Organic b fraction in OCW.

contents of hays with various analytical values.

Regressions relating to ADF and crude fiber were found to be insufficiently accurate to estimate TDN. Multiple regression equation relating to the contents of OCC+Oa and ADF or Ob gave better results than other regressions.

Chemical composition and estimated TDN of tropical grasses

Table 12 shows data on the cell wall components obtained by detergent analysis in Bahia grass, Rhodes grass, finger millet, fall panicum, Makarikari grass and green panic. Large differences in silica and lignin contents depending on the grass species and cutting schedule were observed.

Table 13 shows the composition of tropical grasses based on the combination of proximate analysis and enzymatic analysis. In this table, NCWFE was the fraction representing non-structural carbohydrates such as sugars and starch. TDN contents and voluntary intake of tropical grasses are shown in Table 14. Mean TDN value of second cutting grasses grown in a high temperature in the summer season was 57% and this value was lower than that of the first cutting. In this table, dry matter intake was calculated from the following equation reported by Mertens :

DM intake ($g/kg^{0.75}$/day)$=128.8-1.09$ CW (g/100 g DM)

The low digestibilities of tropical grasses are considered to be due to their high lignin and silica contents (Minson, 1971). In the enzymatic system,Ob fraction is lignified and a portion of cell walls undergoes a process of silicification.

Digestibility of Ob in tropical grasses requires further studies.

Table 10 TDN contents and digestibilities of various fractions obtained by enzymatic analysis of grass hay or mixed hay

% DM or %

Forage No.	TDN	Digestibilities				
		OCC	OCW	Oa	Ob	OCC+Oa
1	67.3	82.5	62.6	96.9	24.6	87.8
2	66.5	79.8	63.7	98.7	36.2	87.8
3	53.3	69.7	52.5	98.3	37.7	81.3
4	57.2	73.0	59.0	96.9	36.0	83.4
5	59.8	74.4	59.4	98.8	34.9	85.0
6	63.0	77.4	60.8	97.0	39.1	84.8
7	38.0	43.2	44.1	68.3	39.4	54.8
8	59.3	68.0	58.0	94.9	43.3	78.6
9	56.9	68.5	53.7	94.4	39.5	78.3
10	61.2	73.5	60.9	95.4	40.9	81.9
11	53.3	67.0	53.3	89.6	43.8	74.2
12	56.1	69.5	58.2	93.6	48.1	77.3
13	57.9	67.5	60.1	100.0	46.4	90.5
14	59.1	73.3	60.7	100.0	46.1	84.5
15	59.4	61.3	65.7	99.4	51.8	80.3
16	62.9	80.3	59.0	94.2	48.2	84.1
17	58.7	78.4	53.2	95.0	42.2	83.4
18	56.2	68.5	55.5	92.1	47.0	77.9
19	66.9	81.5	61.6	88.1	48.0	84.2

OCC : Organic cellular contents, OCW : Organic cell walls,
Oa : Organic a fraction in OCW, Ob : Organic b fraction in OCW,
Mean value with 2-4 animals (sheep or goat).

Table 11 Regression equations and correlation coefficients (r) for estimating TDN contents of grass or mixed hay with various analytical values

Method and regression equation	r	Se
1 Regression equation with one variable		
TDN = −0.971ADF + 94.2	−0.62	5.2
TDN = −1.199CF + 95.8	−0.60	5.3
TDN = 0.748OCC + 37.8	0.81	3.9
TDN = 0.563 (OCC + Oa) + 32.9	0.88	3.2
2 Regression equation with two variables		
TDN = 1.239OCC + 0.583OCW − 12.0	0.87	3.3
TDN = 0.550OCC + 0.588Oa + 32.8	0.88	3.2
TDN = 0.671OCC − 0.065Ob + 42.8	0.79	4.1
TDN = 0.939OCC + 0.382ADF + 18.5	0.82	3.8
TDN = 1.111 (OCC + Oa) + 0.605Ob − 18.8	0.93	2.4
TDN = 0.950 (OCC + Oa) + 1.070ADF − 24.0	0.94	2.3

Se : Standard error of estimate, ADF : Acid-detergent fiber,
CF : Crude fiber, OCC : Organic cellular contents,
OCW : Organic cell wall, Oa : Organic a fraction in OCW,
Ob : Organic b fraction in OCW.

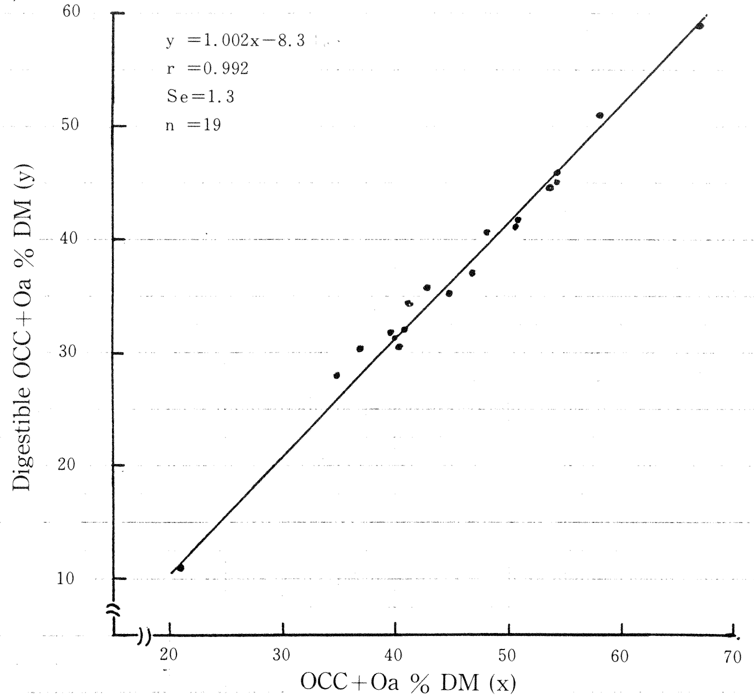

Fig. 6 Relationships between the contents of OCC +Oa and digestible amounts of hay.

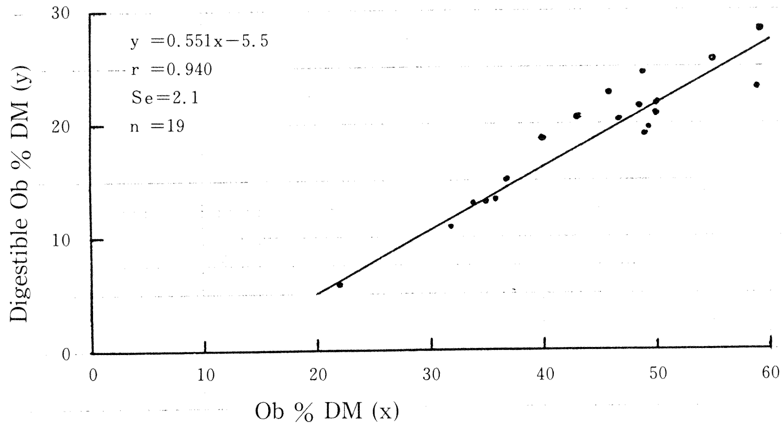

Fig. 7 Relationships between the contents of Ob and digestible amounts of hay.

Table 12 Cell wall fractions obtained by detergent analysis of tropical grasses

% DM

Grass		DM		ADF	Lignin	Silica
		CC	CW			
Bahia grass	1	36.9	63.1	29.6	2.9	2.9
	2	31.6	68.4	35.8	3.2	3.1
	3	29.6	70.4	37.6	4.0	3.5
Rhodes grass	1	31.1	68.9	36.9	3.8	2.4
	2	27.5	72.5	39.6	4.5	2.8
	3	29.3	70.7	35.5	3.9	4.9
Finger millet	1	41.5	58.5	31.7	2.6	1.0
	2	41.8	58.2	32.9	3.0	1.7
	3	40.0	60.0	29.4	2.2	2.0
Fall panicum	1	47.2	52.8	24.7	2.8	1.4
	2	41.8	58.2	30.5	3.4	1.9
	3	41.1	58.9	28.7	3.4	2.5
Makarikari grass	1	43.7	56.3	27.2	2.8	2.8
	2	31.7	68.3	39.7	4.4	4.3
	3	39.6	60.4	29.1	3.0	6.4
Green panic	1	40.2	59.8	32.0	3.4	2.4
	2	32.0	68.0	40.5	5.2	3.3
	3	37.4	62.6	33.5	3.8	4.5

CC : Cellular contents, CW : Cell wall,
1 : First cutting, 2 : Second cutting, 3 : Third cutting.

Forage testing and feed program system

Development of forage evaluation methods is available for all branches of feed science. One of the purposes of TDN assessment of forage is to apply it to a feeding program for cattle.

In the United States a system of forage testing and feeding program has been established for a long time. Recently, in Japan, forage testing for dairy farm has been initiated in many locations.

Figure 8 shows an example of forage testing network in the Tokachi district. Feed samples are sent to a forage analytical center by extension specialists who belong to the agricultural cooperative of each district. Near-infrared radiation analysis and mineral analysis are carried out in this center. Results of analysis are reported to the dairy farmers and extension workers within 10 days.

At the same time, the information on feed value such as dry matter, crude protein, TDN, ADF, Ca and P contents is sent to a computer center for designing a feed program (Table 15).

Near-infrared spectrometry is used for the determination of the organic components of feed based on enzymatic analysis (OCC, OCW, Oa and Ob), ADF, crude protein, ether extracts and starch. TDN is calculated by the regression equation in which the contents of OCC+Oa and Ob are included, as shown in Table 11.

Table 13 Feed composition of tropical grasses based on the combination of enzymatic analysis and proximate analysis

% DM

Grass	OM	OM		OCW		Crude protein	Ether extracts	NCWFE
		OCC	OCW	Oa	Ob			
Bahia grass								
1	89.5	31.9	57.6	17.3	40.3	22.8	3.4	11.4
2	90.3	25.3	65.0	17.9	47.1	13.7	2.4	12.7
3	90.4	25.1	65.3	16.7	48.6	12.7	2.3	13.9
Rhodes grass								
1	88.8	24.2	64.6	18.6	46.0	16.9	2.9	7.3
2	89.0	21.2	67.8	17.5	50.3	14.5	2.2	7.2
3	86.7	23.0	63.0	18.4	44.6	15.1	2.5	9.1
Finger millet								
1	85.6	29.7	55.9	18.0	37.9	23.3	2.9	6.5
2	86.1	30.2	55.9	15.3	40.6	20.1	2.6	10.2
3	87.6	35.3	52.3	14.0	38.3	17.3	2.4	18.4
Fall panicum								
1	90.7	40.2	50.5	20.1	30.4	26.3	4.2	13.4
2	89.6	33.2	56.4	19.0	37.4	17.5	3.2	14.8
3	91.1	35.8	55.3	18.2	37.1	14.5	2.8	21.0
Makarikari grass								
1	89.0	37.3	51.7	23.2	28.5	23.6	3.0	15.6
2	87.9	22.6	65.3	20.8	44.5	16.1	1.9	7.7
3	85.5	34.5	51.0	17.4	33.6	17.8	2.3	18.9
Green panic								
1	87.7	31.4	56.3	23.6	32.7	22.7	3.1	9.4
2	88.2	23.0	65.2	19.9	45.3	16.1	2.1	7.6
3	86.9	28.4	58.5	22.7	35.8	13.5	2.5	15.2

OM : Organic matter, OCC : Organic cellular contents, OCW : Organic cell wall,
Oa : organic a fraction in OCW, Ob : Organic b fraction in OCW,
NCWFE : Nitrogen CW free extracts,
1 : First cutting, 2 : Second cutting, 3 : Third cutting.

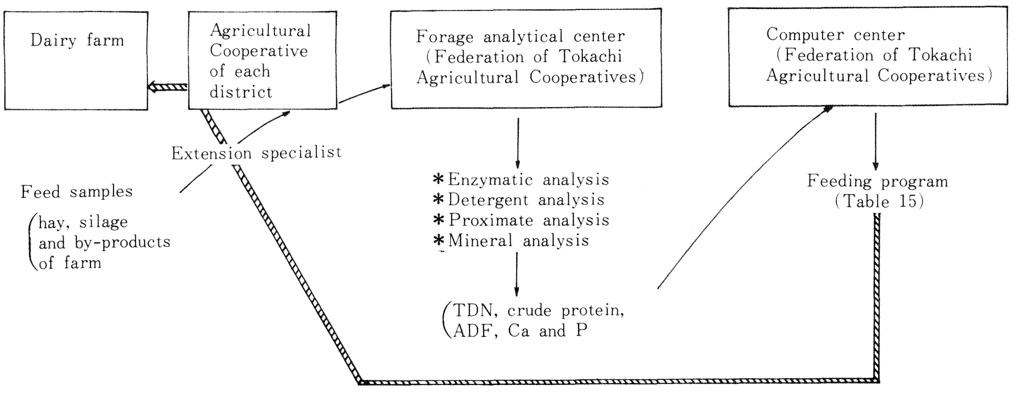

Fig. 8 Example of forage testing and application to feeding program system in Japan. Tokachi Dairy Herd Improvement Organization.

Table 14 TDN contents and voluntary intake of tropical grasses predicted by enzymatic analysis and detergent analysis

Grass		TDN % DM	DMI $g/kg^{0.75}$/day
Bahia grass	1	60.2	60.0
	2	57.7	54.2
	3	57.0	52.1
Rhodes grass	1	56.6	53.7
	2	54.6	49.8
	3	55.0	51.7
Finger millet	1	57.1	65.0
	2	56.3	65.4
	3	59.1	63.4
Fall panicum	1	66.6	71.2
	2	61.8	65.4
	3	63.6	67.6
Makarikari grass	1	65.7	67.4
	2	56.3	54.4
	3	59.2	63.0
Green panic	1	62.1	63.6
	2	56.3	54.7
	3	59.6	60.6

DMI : Dry matter intake,
1 : First cutting, 2 : Second cutting, 3 : Third cutting.

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Table 15 Feed program system sheet developed by Tokachi Dairy Herd Improvent Organization

99 99 simulation 19830901							
Body weight 680 kg Milk fat 3.80		Milk kg/day					
Feed		20.0	25.0	30.0	35.0	40.0	45.0
Grass hay (Timothy first cutting)	(kg/day)	5.0	5.0	5.0	5.0	5.0	5.0
Corn silage	(kg/day)	20.0	20.0	20.0	20.0	20.0	20.0
Beet pulp	(kg/day)	3.0	3.0	3.0	3.0	3.0	3.0
Concentrates (Formula feed)	(kg/day)	5.6	6.8	8.8	11.2	12.0	12.0
Soybean meal	(kg/day)	0.3	0.7	0.7	0.6	1.9	2.0
Price of feed (yen)		958	1074	1218	1372	1547	—
Requirement/fed×100	DM	100.0	100.0	102.3	105.0	106.9	101.2
	TDN	105.3	101.0	100.0	100.0	100.0	92.0
	CP	100.0	100.0	100.0	100.0	108.7	98.9
	ADF	133.2	129.6	129.8	131.0	128.6	121.5
	Ca	112.1	107.0	109.1	112.7	109.5	99.5
	P	98.2	99.5	104.5	109.7	113.8	104.0
Contents %/fed DM	TDN	66.8	67.9	69.0	70.0	71.1	71.1
	CP	12.9	14.2	15.1	15.6	17.6	17.7
	DM/Body weight×100	2.5	2.7	3.0	3.3	3.6	3.6

Feed	Price (yen/kg)	DM	TDN	CP	ADF	Ca	P	Constraints Max.	Const. kg.
			(% DM)						
Timothy first cutting hay	39	88.6	51.2	8.3	42.7	0.34	0.24		5.0
Corn silage	12	26.0	61.5	6.7	20.5	0.04	0.09		20.0
Beet pulp	37	85.9	76.3	10.6	32.6	0.88	0.10	3.0	
Formula feed	69	87.0	80.5	23.0	21.0	0.92	0.69	12.0	
Soybean meal	90	88.2	86.7	52.5	9.2	0.36	0.74	2.0	

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Discussion

Siregar, M.E. (Indonesia): Who is responsible for the forage analyses?

Answer: The determinations are performed in the laboratory of the cooperatives.

Toutain, B. (GERDAT): Is there any organization which carries out forage analyses for the tropical countries?

Answer: For routine analyses the International Feed Information Center in Australia plans to offer such services in future.

Mendoza, R.C. (The Philippines), **Comment:** The quality of the products after harvest largely depends on pre-harvest factors and treatments. Also it would be important to perform routine analyses on toxins and anti-metabolites in the products.

Okubo, T. (Japan), **Comment**: Do you have any data on differences in digestibility between fresh and dried materials? We observed significant differences in the case of subtropical grass species. It would be important to carry out such analyses on fresh materials which are mostly used by the farmers in Southeast Asia.