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Nutritional Evaluation of Crop Residues and Selected Roughages for Ruminants Using *in vitro* Gas Production Technique

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ABSTRACT

Three crop residues and five roughages were selected to evaluate nutritive value using the *in vitro* gas production technique. The rumen mixed microbe inoculums were taken from fistulated Brahman-Thai native crossbred steers. The treatments were 1) water hyacinth (*Eichhorunia crassipes Solms*), 2) kraphanghom (*Paederia foetida Linn*), 3) corn stover (*Zea mays*), 4) cassava hay (*Manihot esculenta Crantz*), 5) sugarcane top (*Saccharum officinarum Linn*), 6) Chinese spinach (*Amaranthus viridis L.*), 7) rice straw (*Oryza sativa*) and 8) cavalcade hay (*Centrosema pascuorum cv. Cavalcade*). The treatments were assigned in order to completely randomize design (four replications). The results indicated that soluble gas fraction (*a*; -2.40, -20.31, -11.96, 0.49, -8.22, -0.99, -16.53 and -2.93 ml, respectively), fermentation of insoluble fraction (*b*; 88.49, 120.31, 111.96, 79.02, 108.62, 76.34, 116.63 and 101.41 ml, respectively), rate of gas production (*c*; 0.014, 0.075, 0.052, 0.029, 0.035, 0.028, 0.036 and 0.040 %/h, respectively) and potential of extent of gas production ($|a|+b$; 90.89, 140.63, 123.07, 78.53, 117.24, 77.33, 133.07 and 104.34 ml, respectively) were significantly different ($P<0.01$) between treatments. These results implied that kraphanghom, rice straw, corn stover, Chinese spinach and cavalcade hay are highly digestible in the rumen. Importantly, crops residues and selected roughages are abundant and available for feeding the ruminants in dry season. These nutritive values provides helpful consideration when developing ruminant production systems.

Keywords: crop residue, roughage, *in vitro*.

1. INTRODUCTION

A major constraint to livestock production in tropical areas is the scarcity and fluctuating quantity and quality of the year-round feed supply. Particularly during dry season, the natural pastures drop in quantity and quality, especially in energy and nitrogen content. As a consequence, feed intake declines and animal productivity is deteriorated. Moreover, tropical forages have a large proportion of lignified cell walls with low fermentation rates and digestibility, which leads to low rates of passage and limited intake [1, 2].

The degree of nutrient degradation occurring in the rumen is a major influence on total utilization of a nutrient in ruminant. Therefore, reliable fast and inexpensive techniques are required to quantify both rate and extent of nutrient degradation from different feed resources in the rumen. The *in vitro* gas production techniques has proved to be a potentially useful rapid technique for feed evaluation [3-6], as it is capable of measuring rate and extent of nutrient degradation [7, 8]. In addition, the *in vitro* gas production technique is less expensive

[6], easy to determine,[9] and suitable for use in developing countries [10].

In spite of numerous studies conducted on the used of crop residue as ruminant feed [11,12], limited information is available on the kinetics of digestion and metabolizable energy for ruminant using the *in vitro* gas production technique. There is also little research that characterizes individual feeds that used on small scale farm. Therefore, the aim of this study was to assess the chemical composition and kinetics of gas production of crop residues and selected roughages.

2. MATERIALS AND METHODS

2.1 Crop Residues and Selected Roughages Preparation and Analysis

The crop residues and selected roughages were: 1) water hyacinth (*Eichhorunia crassipes Solms*), 2) kraphanghom (*Paederia foetida Linn*), 3) corn stover (*Zea mays*), 4) cassava hay (*Manihot esculenta Crantz*), 5) sugar cane top (*Saccharum officinarum Linn*), 6) Chinese spinach (*Amaranthus viridis L.*), 7) rice straw (*Oryza sativa*) and 8) cavalcade hay (*Centrosema pascuorum cv. Cavalcade*). They were collected from beef and dairy farms at Maha-sarakham province, North-East of Thailand. Fresh samples (1 kg) were hand harvested from three different specimens. Duplicate fresh samples (0.5 kg/replicate) were dried in a hot, dry air force oven at 65 °C for 72 h and weighed. The samples (Table1) were then ground to pass through a 1 mm screen for *in vitro* incubation and chemical analysis. The samples were analyzed for dry matter (DM), crude protein (CP) and ash content [13]. Neutral detergent fiber (NDF), acid detergent fiber (ADF) and acid detergent lignin (ADL) were assayed using the method proposed by Van Soest *et al.* [14].

2.2 Experimental Design

The experimental design was completely randomized design with four replications. The treatments included water hyacinth (*Eichhorunia crassipes Solms*), kraphanghom (*Paederia foetida Linn*), corn stover (*Zea mays*), cassava hay (*Manihot esculenta Crantz*), sugarcane top (*Saccharum officinarum Linn*), Chinese spinach (*Amaranthus viridis L.*), rice straw (*Oryza sativa*), and cavalcade hay (*Centrosema pascuorum cv. Cavalcade*). Strict anaerobic techniques were used in all procedures during the rumen fluid transfer and incubation period. Rumen fluid inoculums were removed before the morning feeding under vacuum pressure via the rumen fistula into a 2 liter-glass flask and transferred into two pre-warmed 1 liter thermos flasks which were then transported to the laboratory. The medium preparation was as described by Sommart *et al.* [15]. Mixed rumen fluid inoculums were obtained from two fistulated Brahman-Thai native crossbred steers (weighing about 250+15 kg). The animals were offered rice straw on *ad libitum* and fed 0.5 % body weight of concentrate (concentrate mixture: 49.80% cassava chip, 17.5% rice bran, 14.60% palm meal, 7.0% soybean meal, 1.40% urea, 0.4% salt, 1.0 % mineral mix and 8.30% sugar cane molasses). The animals were fed twice a daily, water and a mineral lick were available *ad libitum* for 14 days.

The feed sample of approximately 0.5 g on a fresh weight basis was transferred into a 50 ml serum bottle [15]. The bottles were pre-warmed in a hot air oven at 39 °C for about 1 hour prior to injection of 40 ml of rumen fluid medium (using a 60 ml syringe) to each bottle. The bottles were stoppered with rubbers stoppers, crimp sealed and incubated in a hot air oven set at 39 °C.

The rate of gas production was measured by reading and recording the amount of gas volume after incubation using a 20 mL glass syringe connected to the incubation bottle with a 23 gauge, 1.5 inch needle. Readings of gas production were recorded from 1 to 96 h (hourly from 1-12 h, every 3 h from 13-24 h, every 6 h from 25-48 h and every 12 h from 49-96 h) after incubation periods. Amount of cumulative gas volume at 3, 6, 12, 24, 48, 72 and 96 h after incubations were fitted using the equation $y= a+b\,[(1-\mathrm{Exp}(-ct)]$ [16], where a= the intercept, which ideally reflects the fermentation of the soluble fraction, b= the fermentation of the insoluble fraction, *c*= rate of gas production, ($|a|+b$)= potential extent of gas production, y= gas production at time 't'.

2.3 Statistical Analyses

All data obtained from the trials were subjected to the analysis of variance procedure of statistical analysis system [17] according to a completely randomized design. Means were separated by Duncan New's Multiple Range Test. The level of significance was determined at $P<0.05$.

3. RESULTS AND DISCUSSION

3.1 Chemical Composition of Crop Residues and Selected Roughages

The chemical compositions of crop residues and selected roughages are presented in Table 1. The crude protein content of the crop residues and selected roughage ranged from 3.0 to 26.42 %. Rice straw had the lowest crude protein content while the Chinese spinach had the highest crude protein content. Similar crude protein content were observed in krapanghom (16.62 %) and cassava hay (15.79 %). When comparing crude protein content of krapanghom and cassava hay with alfalfa hay as reported by [18], it was found that the crude protein content of krapanghom, cassava hay and alfalfa hay were similar. Low protein content was observed in crop residues (corn stover, sugarcane top and rice straw). The results of this study agrees with reports by Hindrichson *et al.* [2] who reported that most crop residues in temperate zone were low in protein and high in fibrous content. The crude protein content of rice straw was lower than that reported by Liu *et al.* [19], but was similar to that reported by Keir *et al.* [20]; Department of Livestock Development [21]. The crude protein content of cassava hay was lower than that reported by Promkot and Wanapat [22] and Wanapat *et al.* [23]. The difference of crude protein content was probably due to the maturity level and leaves-stem ratio of cassava hay. The crude protein content of cassava hay decreased as maturity increased [23].The crude protein content of sugarcane top was higher than that reported by Kawashima *et al.* [24], but similar to that reported by Bui *et al.* [25]. Crude

Table 1. Chemical composition of crop residues and selected roughages.

Feedstuffs[1]	DM, (%)	CP	Ash	NDF	ADF	ADL
	…………..%DM basis…………….					
Crop residue						
CS	23.33±0.03	6.27±0.77	6.33±0.12	67.35±1.35	38.36±0.06	4.08±0.13
SC	36.67±0.03	5.81±0.10	5.27±0.01	79.93±1.90	54.61±0.12	8.94±0.35
RS	91.50±0.01	3.00±0.05	13.64±0.03	72.13±1.08	53.28±0.11	4.89±0.29
Selected roughage						
WH	15.00±0.19	12.97±0.32	14.30±0.47	69.23±0.91	42.69±2.12	3.67±0.71
KH	21.67±0.08	16.62±0.14	8.55±0.02	50.19±0.37	45.26±0.10	11.75±0.70
CH	24.00±0.01	15.79±0.63	8.73±0.11	50.97±1.98	48.43±0.56	12.64±0.60
CN	15.55±0.04	26.42±0.02	23.31±0.10	40.06±0.01	19.96±0.67	4.99±0.03
CC	94.48±0.01	10.99±0.29	7.63±0.21	59.90±2.93	41.64±0.54	11.52±1.82

DM= dry matter, CP= crude protein, NDF= neutral detergent fiber, ADF= acid detergent fiber and ADL= acid detergent lignin

[1] WH = water hyacinth (*Eichhorunia crassipes Solms*), KH = kraphanghom (*Paederia foetida Linn*), CS = corn stover (*Zea mays*),CH = cassava hay (*Manihot esculenta Crantz*), SC = sugarcane top (*Saccharum officinarum Linn*), CN = Chinese spinach (*Amaranthus viridis L.*), RS = rice straw (*Oryza sativa*), CC = cavalcade hay (*Centrosema pascuorum cv. Cavalcade*)

protein content of corn stover was also higher than that reported by Hindrichson *et al.* [2] and Mgheni *et al.* [26]. There are many factors that affect crude protein content such as stage of growth [22] maturity and species or variety [27] and soil types [28]. These factors may partially explain differences in crude protein content between our study and others.

Ash content of crop residue and selected roughages ranged from 5.27 to 23.31%. Sugarcane top had the lowest ash content while the Chinese spinach had the highest. The ash content of rice straw was lower than that reported by Department of Livestock Development [21], but higher than that reported by Liu *et al.* [19]. The difference of ash content was probably due to variety of rice straw [12] and soil type [29]. However, ash content of rice straw was similar to that reported by Fonseca *et al.* [30] and Thu and Preston [29]. The ash content of corn stover was lower than that reported by Hindrichson *et al.* [2] and Magheni *et al.* [26]. Ash content of sugarcane top, water hyacinth and cassava hay were similar to previous reports [23, 24, 29].

Neutral detergent fiber content of crop residues and selected roughages ranged from 40.06 to 79.93%. Chinese spinach had the lowest NDF content while sugarcane top had the highest. Similar NDF content was observed in water hyacinth, corn stover and rice straw. The NDF content of rice straw was higher than that reported by Department of Livestock Development [21] and Fonseca *et al.* [30], but similar to that reported by Liu *et al.* [19]. The NDF content of corn stover was lower than that reported by Hindrichson *et al.* [2]. Neutral detergent fiber contents of sugarcane top, water hyacinth and krapanghom were all similar to previous reports [21, 24, 29]

Acid detergent fiber content of crop residues and selected roughages ranged from 19.96 to 54.61%. Chinese spinach had the lowest ADF content while the sugarcane top had the highest. Similar ADF content were observed in water hyacinth, krapanghom and cavalcade hay. The ADF content of rice straw was higher than that reported by Department of Livestock Development [21] and Thu and Preston [29], but similar to that reports by Liu *et al.* [19]. The ADF content of corn stover was similar to that reported by Department of Livestock Development [21]. Acid detergent fiber contents of water hyacinth and sugarcane top were higher than those previous reported [24, 29].

There are many factors that may affect fibrous (NDF and ADF) content such as stage of growth (Promkot and Wanapat, 2004), maturity and species or variety [12, 27], drying method, growth environment [31] and soil types [29]. These factors may partially explain differences in fibrous content between our study and others.

Acid detergent lignin content of crop residue and selected roughages ranged from 3.67 to 12.64 %. Water hyacinth had the lowest ADL content; cassava hay had the highest. Similar ADL content were observed in corn stover, Chinese spinach and rice straw. The ADL content of rice straw was lower than that reported by Thu and Preston [29], but similar to other previous reports [21,30]. The difference of ADL content was probably due to difference in variety of rice straw [12] and soil type [29].

3.2 Gas Production Characteristics of Crop Residues and Selected Roughages

Gas production from the fermentation of crop residues and selected roughages were measured at 3, 6, 12, 24, 48, 72 and 96 h. *In vitro* gas tests adapted to describe kinetics of fermentation that were based on the modified exponential model $y= a+b\,[(1-\text{Exp}(-ct)]$ [16]. Although there are other models available to describe the kinetics of gas production, the Ørskov and McDonald [16] model was chosen because the relationship of its parameters with intake, digestibility and degradation characteristic of forages and concentrate feedstuffs had been documented [4, 9, 15, 32].

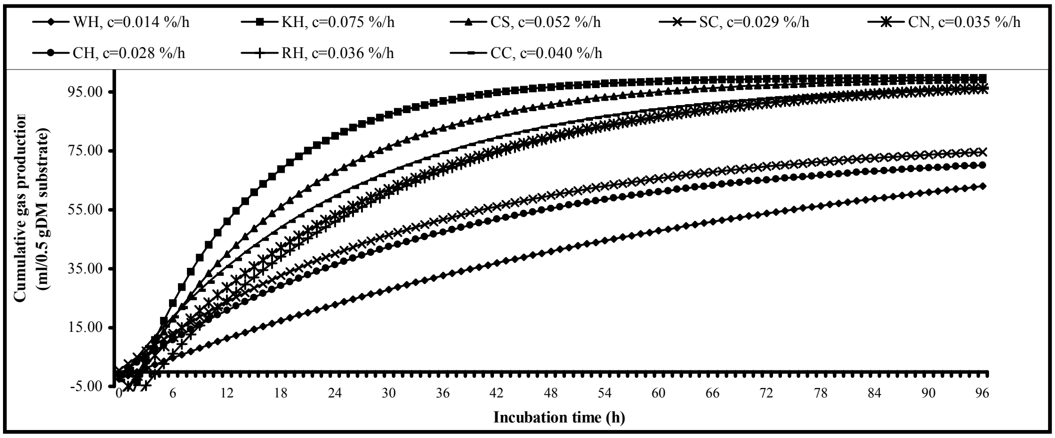

Figure 1. Cumulative gas volume estimated by y= a+b [(1-Exp(-ct)] (ml/0.5 gDM substrate) throughout 96 h. (WH = water hyacinth (*Eichhorunia crassipes Solms*), KH = kraphanghom (*Paederia foetida Linn*), CS = corn stover (*Zea mays*),CH = cassava hay (*Manihot esculenta Crantz*), SC = sugarcane top (*Saccharum officinarum Linn*), CN = Chinese spinach (*Amaranthus viridis L.*), RS = rice straw (*Oryza sativa*), CC = cavalcade hay (*Centrosema pascuorum cv. Cavalcade*)).

Gas production characteristics are presented in Table 2 and Figure 1. A comparison of the gas production characteristics of different treatments indicated significant differences between them ($P<0.01$). The value for *a* intercept for all feeds ranged from –20.31 to 0.49 ml. Kraphanghom had the lowest for *a* intercept, while sugarcane top had the highest. The values for *a* intercept were negative in the incubations in this study, with the exception of sugarcane top. These data suggested that a lag phase due to delay in microbial colonization of the substrate may

Table 2. Gas production characteristics, gas volume and estimated metabolizable energy of crop residues and selected roughages.

Parameters	Treatment[1]								
	WH	KH	CS	SC	CN	CH	RS	CC	SEM
Gas production characteristic parameters[2]									
a, ml	-2.40^{a}	-20.31^{d}	-11.96^{bc}	0.49^{a}	-8.22^{b}	-0.99^{a}	-16.53^{cd}	-2.93^{a}	1.41
b, ml	88.49^{e}	120.31^{a}	111.96^{ab}	79.02^{c}	108.62^{ab}	76.34^{c}	116.63^{a}	101.41^{b}	3.13
c, %/h	**0.014^{d}**	**0.075^{a}**	**0.052^{b}**	**0.029^{c}**	**0.035^{c}**	**0.028^{c}**	**0.036^{c}**	**0.040^{bc}**	**0.001**
|*a*| +*b*, ml	**90.89^{de}**	**140.63^{a}**	**123.07^{ab}**	**78.53^{e}**	**117.24^{bc}**	**77.33^{e}**	**133.07^{ab}**	**104.34^{cd}**	**4.40**
Gas production (ml/0.5g DM substrate)									
24 h	18.50^{e}	71.10^{a}	63.25^{ab}	38.50^{cd}	38.87^{cde}	34.00^{cde}	24.25^{de}	49.12^{bc}	3.62
48 h	38.75^{c}	98.10^{a}	103.63^{a}	61.0^{bc}	61.88^{bc}	57.13^{bc}	56.75^{bc}	74.50^{ab}	4.77
96 h	68.63^{c}	113.23^{ab}	138.13^{a}	73.25^{c}	92.38^{bc}	69.13^{c}	101.13^{bc}	91.88^{bc}	5.29

[a, b, c, d, e] Means within rows not sharing common superscripts are significantly different (P<0.01)

[1] WH = water hyacinth (*Eichhorunia crassipes Solms*), KH = kraphanghom (*Paederia foetida Linn*), CS = corn stover (*Zea mays*),CH = cassava hay (*Manihot esculenta Crantz*), SC = sugarcane top (*Saccharum officinarum Linn*), CN = Chinese spinach (*Amaranthus viridis L.*), RS = rice straw (*Oryza sativa*), CC = cavalcade hay (*Centrosema pascuorum cv. Cavalcade*)

[2] *a*= the intercept (ml), which ideally reflects the fermentation of the soluble fraction, *b*= the fermentation of the insoluble fraction (asymptote) (ml), *c*= rate of gas production (%/h), |*a*|+*b*= potential extent of gas production (ml)

occur in the early state of incubation. Several authors [4, 9] have also reported negative values with various substrates when using mathematical models to fit gas production kinetics. This is due to either a deviation from the exponential cause of fermentation or delays in the onset of fermentation due to microbial colonization. It is well known that the value for absolute *a* (|*a*|), described ideally, reflects the fermentation of the soluble fraction. The soluble fraction could be easily attached by microorganisms in the rumen and increases gas production (Table 2). In this study the absolute *a* was highest for kraphanghom. It was indicated that the soluble fraction in kraphanghom was also highest. High absolute *a* was also observed in rice straw and could be due to structure and solubility characteristics of the fiber in rice straw which easily attach with microorganisms in the rumen. Soluble fractions in crop residues such as sugarcane top and corn stover were lower than rice straw.

The gas volume at asymptote (*b*) described the fermentation of the insoluble fraction. The gas volume at asymptote of kraphanghom, rice straw, corn stover, sugar cane top, cavalcade hay, water hyacinth, cassava hay and Chinese spinach were; 120.31, 116.63, 111.96, 108.62, 101.41, 88.49, 79.02 and 76.34 ml, repetitively. It can be seen that gas production at asymptote of water hyacinth, cassava hay Chinese spinach and cavalcade hay were low when compared the other feed, this result might have been a reflection of the proportion of their fiber component [33] and protein content.

Rate of gas production (*c*,%/h) as ranked from the fastest to the slowest were; kraphanghom, corn stover, cavalcade hay, rice straw, Chinese spinach, sugarcane top, cassava hay and water hyacinth. Fast rates of gas production were observed in kraphanghom and corn stover; possibly due to the influence of carbohydrate fraction readily available to the microbial population. Slowest gas production was observed in water hyacinth, indicating that water hyacinth was less available to rumen microbes. The current findings agree with *in situ* studies on crop residues and selected roughages (Chumpawadee *et al.*, data unpublished).

Potential extent of gas production (|*a*|+*b*) expressed in ml, ranked from highest to lowest were; kraphanghom, rice straw, corn stover, Chinese spinach, cavalcade hay, water hyacinth, sugarcane top and cassava hay. Remarkably, the potential of gas production of water hyacinth, sugarcane top and cassava hay were slightly lower than other feeds. The reason might have been fiber component (Table 1) and protein content proportions. Khazaal *et al.* [34] reported that protein fermentation does not lead to much gas production. Fibrous constituents also negatively influenced in *vitro gas* production [35]. In this study, high potentials for gas production were observed in kraphanghom, rice straw, corn stover, Chinese spinach, cavalcade hay. This implied that kraphanghom, rice straw, corn stover, Chinese spinach, cavalcade hay were highly digestible in the rumen. These results suggested that because of kraphanghom, rice straw, corn stover, Chinese spinach, cavalcade hay are abundant in the dry season, thus they have the advantage for feeding the ruminants in dry season.

3.3 Gas Volumes of Crop Residues and Selected Roughages

The cumulative gas volumes at 24, 48 and 96 h after incubation are shown in Table 2. The results indicate that cumulative gas volumes at 24, 48 and 96 h after incubation were significantly different ($P<0.01$) between treatment. Curves of cumulative gas production for each treatment are presented in Figure 1. It can be seen that gas production reached a plateau after 72 h fermentation. Cumulative gas volume at each sampling time was affected by crop residue variety and selected roughage. These findings indicate that substrate fractions and degradability of crop residue and selected roughage are different. Gas production is directly proportional to substrate degradation rate [36]. Additionally, kinetics of gas production depends on the relative proportions of soluble, insoluble but degraded, and undegradable particles of the feed [37]. Menke *et al.* [38] suggested that gas volume at

24 h after incubation has a relationship with metabolizable energy in feedstuffs. Sommart *et al.* [15] suggested that gas volume is a good parameter from which to predict digestibility, fermentation end-product and microbial protein synthesis of the substrate by rumen microbes in the *in vitro* system. Additionally, *in vitro* dry matter and organic matter digestibility were shown to have high correlation with gas volume [15, 32]. Gas volumes also have shown a close relationship with feed intake [4] and growth rate [10].

4. Conclusions

The crop residues and selected roughages showed great variation in chemical composition. The results in this study demonstrates that kinetics of gas production of crop residues and selected roughages differ between feed. Based on this study, high rumen fermentation potential for crops residues and selected roughages use in ruminants ranked from the highest to the lowest were; kraphanghom, rice straw, corn stover, Chinese spinach, cavalcade hay, water hyacinth, sugarcane top and cassava hay. Importantly, crops residues and selected roughages are abundant and available for feeding the ruminants in dry season.

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References

[1] Ibrahim M.N.M., Tamminga S. and Zemmelink G., Degradation of tropical roughages and concentrate feeds in the rumen, *Anim. Feed Sci.Technol.*, 1995; 54:81-92.

[2] Hindrichsen I.K., Osuiji P.O., Odenyo A.A., Madsen J. and Hvelplund T., Effect of supplementation with four multipurpose trees and *Lablab purpureus* on rumen microbial population, rumen fermentation, digesta kinetics and microbial protein supply of sheep and maize stover *ad libilitum*. *TSAP Proceeding* Vol. 28, 2001.

[3] Menke K. and Steingass H., Estimation of the energetic feed value obtained from chemical analysis and *in vitro* gas production using rumen fluid, *Animal Research and Development.*, 1988; 28:7-55.

[4] Blummel M. and Ørskov E.R., Comparison of *in vitro* gas production and nylon bag degradability of roughages in predicting feed intake in cattle, *Anim. Feed Sci. Technol.*, 1993; 40:109-119.

[5] Herrero M., Murray I., Fawcett R.H. and Dent J.B., Prediction of *in vitro* gas production and chemical composition of kikuyu grass by near- infrared reflectance spectroscopy, *Anim. Feed Sci. Technol.*, 1996; 60:51-67.

[6] Getachew G., Robinson P.H., DePeters E.J. and Taylor S.J., Relationships between chemical composition, dry matter degradation and *in vitro* gas production of several ruminant feeds, *Anim. Feed Sci. Technol.*, 2004; 111:57-71.

[7] Groot J.C.J., Cone J.W., Williums B.A., Debersaques F.M.A. and Lantinga E.A., Multiphasis analysis of gas production kinetics for *in vitro* fermentation of ruminant feeds, *Anim. Feed Sci. Technol.*, 1996; 64:77-89.

[8] Cone J.W., van Galder A.H. and Driehuis F., Description of gas production profiles with a three-phasic model, *Anim. Feed Sci. Technol.*, 1997; 66:31-45.

[9] Khazaal K., Dentinho M.T., Riberiro J.M. and Ørskov E.R. A, comparison of gas production during incubation with rumen contents in vitro and nylon bag degradability as predictors of the apparent digestibility in vivo and the voluntary intake of hays, *Animal Production.*, 1993; 57: 105-112.

[10] Blummel M. and Becker K., The degradability characteristics of fifty-four roughages and roughage neutral detergent fibers as described by in vitro gas production and their relationship to voluntary feed intake, *Br. J. Nutr.*, 1997; 77: 757-768.

[11] Chinh B.V., Ly L.V., Tao N.H., Hai N.V. and Ngoc T.B., Study on processing, storing and using sugarcane leaves as ruminant feed. Workshop-seminar "*Making better use of local feed resources*" SAREC-UAF, January, 2000.

[12] Agbagla-Dohnani A., Noziere P., Clement G. and Doreau M., *In sacco* degradability chemical and morphological composition of 15 varieties of European rice straw, *Anim. Feed Sci. Technol.*, 2001; 94:15-27.

[13] AOAC. Official Methods of Analysis, Vol.1, 15th Edition. *Association of Official Analytical Chemists*, Arlington, Virginia, USA., PP. 69-90. 1990.

[14] Van Soest P.J., Robertson J.B. and Lewis B.A., Methods for dietary fiber, neutral detergent fiber, and non starch polysaccharides in relation to animal nutrition, *J. Dairy Sci.*, 1991; 74:3583-3597.

[15] Sommart K., Parker D.S., Rowlinson P. and Wanapat M., Fermentation characteristics and microbial protein synthesis in an *in vitro* system using cassava, rice straw and dried ruzi grass as substrates, *Asian-Aust. J.Anim. Sci., 2000*; 13(8):1084-1093.

[16] Ørskov E.R. and McDonald I., The estimation of Protein degradability in the rumen from incubation measurements weighted according to rate of passage, *J. Agri. Sci. (Camb).*, 1979; 92:499-504.

[17] SAS. *SAS User's Guide: Statistics*, Version 6.12th Edition. SAS Institute Inc.Cary, NC., 1996.

[18] Alcaide E.M., Martin Garcia A.I. and Aguilera J.F., A comparative study of nutrient digestibility, kinetics of degradation and passage and rumen fermentation pattern in goats and sheep offered good quality diets, *Livestock Production Science.*, 2000; 64:215-223.

[19] Liu J.X., Susenbeth A. and Sudekum K.H., *In vitro* gas production measurement to evaluate interactions between untreated and chemically treated rice straws, grass hay, and mulberry leaves, *J. Anim. Sci.*, 2002; 80:517-524.

[20] Keir B., Lai N.V., Preston T.R., and Ørskov E.R., Nutritive value of leaves from tropical trees and shrubs: 1. *In vitro* gas production and *in sacco* rumen degradability, *Livestock Research for Rural Development.*, 1997; 9(4):1-8.

[21] Department of Livestock Development, Ministry of Agricultural and Cooperative. *Table of Chemical Composition of Feedstuffs.* Chumnum Sahakorn HeangpradhesThai Ltd. 2004.

[22] Promkot C. and Wanapat M., Ruminal degradation and intestinal digestion of crude protein of tropical resources using nylon bag and three-step *in vitro* procedure in dairy Cattle. *Proceedings of the Agricultural Seminar, Animal Science/Animal Husbandry.* Held at Sofitel Raja Orchid Hotel 27-28 January, 2004.

[23] Wanapat M., Pimpa O., Petlum A. and Boontao U., Cassava hay: A new strategic feed for ruminant during the dry season, *Livestock Research for Rural development.*, 1997; 9:1-5.

[24] Kawashima T., Sumamal W., Pholsen P., Chaithiang R., Boonpakdee W., Kurihara M. and Shibata M., Feeding value of sugarcane stalk for cattle, *Asian-Aust. J. Anim. Sci.*, 2002; 15(1):55-60.

[25] Bui X.A., Hieu L.T. and Preston T.R. Multrinutrient blocks (MUB) as supplement of milking cows fed forages of low nutritive value in South Vietnam, *Livestock Research for Rural Development.*, 1993; 5(1):1-5.

[26] Mghani D.M., Ndemanisho E.E., Hvelplund T. and Weisbjerg M. Evaluation of the feeding value of two tropical cereal straw, maize stover, rice straw and their botanical fractions by nylon and mobile bag technique, *African Journal of Science and Technology (AJST).*, 2001; 2:65-71.

[27] von Keyserlingk M.A.G., Swift M.L., Puchala. R. and Shelford V., Degradability characteristics of dry matter and crude protein of forages in Ruminants, *Anim. Feed Sci. Technol.*, 1996; 57:291-311.

[28] Baloyi J.J., Ngongoni N.T., Topps J.H. and Ndlovu P., Chemical composition and degradability of *Brachystegia spiciformis* (Musasa) leaves and stems harvested over 4 months from three site in Zimbabwe, *Anim. Feed Sci. Technol.*, 1997; 69:179-186.

[29] Thu N.V. and Preston T.R., Rumen environment and feed degradability in swamp buffaloes fed different supplements, *Livestock Research for Rural Developmen.*, 1999; 11(3):1-7.

[30] Fonseca A.J.M., Daias-da-Silva A.A. and Ørskov E.R., *In sacco* degradation characteristics as predictors of digestibility and voluntary intake of roughages by mature ewes, *Anim. Feed Sci. and Technol.*, 1998; 72:205-219.

[31] Mupangwa J.F., Ngongoni N.T., Topps J.H. and Ndlovu P., Chemical composition and dry matter of forage legumes *Cassia rotundiforlia cv.* Wynn, *Lablab purpureus cv.* Highworth and *Macroptilium atropurpureum cv.* Siratro at 8 weeks of growth (pre-anthesis), *Anim. Feed Sci. Technol.*, 1997; 69:167-178.

[32] Nitipot P. and Sommart K., Evaluation of ruminant nutritive value of cassava starch industry by products, energy feed sources and roughages using in vitro gas production technique. *Proceeding of Annual Agricultural Seminar for year 2003*, 27-28 January, KKU. 179-190. 2003.

[33] Nherera F.V., Ndlovu L.R. and Dzowela B.H., Relationships between *in vitro* gas production characteristics, chemical composition and *in vivo* quality measures in goats fed tree fodder supplements, *Small Ruminant Research.*, 1999; 31:117-126.

[34] Khazaal K., Dentinho M.T., Ribeiro J.M. and Ørskov E.R., Prediction of apparent digestibility and voluntary feed intake of hays fed to sheep: Comparison between using fiber component, *in vitro* digestibility or characteristics of gas production or nylon bag degradation, *Anim. Sci.*, 1995; 61:521-538.

[35] Melaku S., Peters K.J. and Tegegne A., *In vitro* and *in situ* evaluation of selected multipurpose trees, wheat bran and *Lablab purpureus* as potential feed supplements of tef (*Eragrostis tef*) straw, *Anim. Feed Sci. Technol.* 2003; 108:159-179.

[36] Dhanoa M.S., Lopez S. and Dijkstra J., Estimating the extent of degradation of ruminant feeds from a description of their gas production profiles observed *in vitro*: Comparison of models, *Br. J. Nutri.*, 2000; 83:131-142.

[37] Getachew G., Blummel M., Makkar H.P.S. and Becker K., *In vitro* gas measuring techniques for assessment of nutritional quality of feeds: A review, *Anim. Feed Sci. Technol*, 1998; 72:261-281.

[38] Menke K.H., Raab L., Salewski A., Steingrass H., Fritz D. and Schneider W., The estimation of the digestibility and metabolizable energy content of ruminant feedstuffs from the gas production when they are incubated with rumen liquor, *J. Agri. Sci.*, 1979; 93:217-222.