

**PENGARUH SUHU LINGKUNGAN DAN KETERSEDIAAN AIR MINUM TERHADAP
KECERNAAN PAKAN, PRODUKSI NITROGEN MIKROBA RUMEN
DAN KONDISI RUMEN PADA DOMBA**

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INTISARI

Suatu percobaan telah dilaksanakan untuk mengkaji konsumsi dan pemanfaatan pakan, serta kondisi rumen pada domba yang berada dalam suhu lingkungan yang tinggi dan ketersediaan air minum yang terbatas. Sebanyak 16 ekor domba jantan kastrasi dari bangsa Border Leicester x Merino (umur 3 tahun, bobot $58 \pm 2,2$ kg) secara acak dialokasikan dalam sebuah Rancangan Acak Lengkap dengan struktur faktorial 2×2 . Perlakuan yang diterapkan adalah suhu lingkungan (20° atau $40^\circ/32^\circ\text{C}$) dan ketersediaan air minum (*ad libitum* atau 50% dari *ad libitum*). Tidak terdapat interaksi yang nyata antara suhu lingkungan dan ketersediaan air pada semua indikator yang dicatat. Suhu lingkungan yang tinggi menurunkan efisiensi produksi protein mikroba, dan meningkatkan laju pernafasan, suhu rektal dan lama kontraksi rumen, tetapi tidak berpengaruh terhadap konsumsi bahan kering, produksi mikroba rumen, volume rumen, laju pengaliran cairan rumen, konsentrasi asam lemak mudah terbang, ataupun konsentrasi amonia. Keterbatasan air minum menekan konsumsi bahan kering, meningkatkan kecernaan bahan kering, menurunkan volume rumen dan laju aliran cairan rumen, menurunkan frekuensi kontraksi rumen dan meningkatkan konsentrasi asam asetat, serta meningkatkan imbalanced asetat : propionat dalam cairan rumen. Disimpulkan bahwa pengaruh keterbatasan air minum terhadap konsumsi pakan diperantarai oleh perubahan motilitas rumen dan laju aliran cairan rumen, dan pengaruh ketersediaan air minum terhadap kecernaan pakan terjadi secara tidak langsung melalui perubahan konsumsi pakan.

(Kata kunci : Domba, Suhu lingkungan, Ketersediaan air, Pemanfaatan pakan, Kondisi rumen).

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THE EFFECTS OF AMBIENT TEMPERATURE AND WATER AVAILABILITY ON FEED DIGESTIBILITY, RUMEN MICROBIAL NITROGEN PRODUCTION AND RUMEN CONDITION IN SHEEP

ABSTRACT

An experiment was carried out to investigate feed intake, feed utilisation and rumen condition in sheep under high ambient temperature and restricted water availability. Sixteen ruminally cannulated Border Leicester x Merino wethers (aged 3 years, weighing 58 ± 2.2 kg) were randomly allocated in a 2 x 2 factorial structure of completely randomised design. Treatments applied were ambient temperature (20° or 40°/32°C) and water availability (*ad libitum* or 50% of *ad libitum*). There were no significant interactions between temperature and watering regime for any of the indices recorded. High temperature decreased efficiency of microbial nitrogen production (EMNP), and increased respiration rate (RR), rectal temperature (RT) and the length of rumen contractions, but did not affect dry matter intake (DMI), microbial nitrogen production (MNP), rumen volume, liquid outflow rate (LOR), rumen volatile fatty acid (VFA) or rumen NH_3 concentrations. Water restriction depressed dry matter intake (DMI), increased dry matter digestibility (DMD), reduced rumen volume and liquid outflow rate from the rumen (LOR), decreased the frequency of rumen contractions, and increased the acetate concentration and the acetate: propionate ratio in rumen fluid. It was concluded that the effect of restricted WI on FI was mediated by changes in rumen motility and LOR, and that its effect on digestibility was an indirect one through FI.

(Key words : Sheep, Ambient temperature, Water availability, Feed utilisation, Rumen condition).

Introduction

One of the problems with ruminant production in the tropics is feed quality, for temperature and solar radiation are high throughout the year and forages thus mature very quickly and are characterized by high lignin contents (Van Soest, 1994). In turn, the digestibility and nutritive value of forages decrease as the plants mature (Winugroho *et al.* 1990). In addition, during the dry season fresh forage is in limited supply, and at that time the ruminant is commonly fed almost entirely on a low-quality roughage-based diet, such as rice straw. Such low-quality feeds mean that ruminants frequently cannot even maintain body weight (BW), let alone achieve their maximum production levels, unless appropriate feed supplementation is practised (Leng, 1990).

At high temperatures, animals face difficulties in dissipating the heat which results from body metabolism (including the heat

increment (HI) of digestion) and from elements of the environment such as radiation and conduction (NRC, 1981). If animals are unable to dissipate this heat by conduction, convection, evaporation, and radiation, they tend to reduce their feed intake (FI) in order to reduce heat production (HP) and thus maintain their body temperature within the thermoneutral range (Mount, 1979). In tropical countries, such as Indonesia, where both environmental temperature and humidity are commonly high, ruminants tend to experience a low FI under field conditions (Leng, 1990) and, as a result, live weight gain (LWG) is low.

The objectives of the current experiment were to investigate the effects of temperature and water intake (WI) on dry matter intake (DMI) and digestibility (DMD), microbial nitrogen production (MNP) and its efficiency (EMNP), rumen liquid outflow rate (LOR), rumen volatile fatty acid (VFA) and NH_3 concentrations, and rumen motility in sheep.

Materials and Methods

Animals, experimental design and diet

Sixteen ruminally cannulated Border Leicester x Merino wethers (58±2.2 kg), aged 2 years, were used in this experiment. They were allocated into a 2x2 factorial structure in a completely randomised design. The treatments applied were ambient temperature (2 levels: 20° and 40°C) and water availability (2 levels: *ad libitum* and restricted, the latter to half of the mean intake of each individual between d 6 and d 9). The sheep were fed *ad libitum* on oaten chaff, which contained 93.3 % OM and 1.65 % N on a DM basis.

Procedures

The sheep were penned individually in metabolism crates, 8 crates in each of 2 temperature controlled rooms which were maintained at 20°C (ranging from 19° to 21°C) and 40% RH during a 5-d adjustment period (d 1 to d 5). Lighting was from 06.00 till 18.00 h daily. Feed and water were provided *ad libitum* during the adjustment period and FI and WI were monitored daily. Feed was replaced with fresh material every day at 09.00 h, when refusals were weighed, after which the feed was replenished at 13.00 and 17.00 h so as to maintain its availability at an *ad libitum* level.

On d 6 the temperature of one chamber was increased to 40°/32°C (ranging from 39° to 41°C during the day and from 31° to 33°C at night), while the other chamber was maintained at 20°C (19°-21°C); RH in both cases was set at 40%. The lighting regime was unchanged. At this stage drinking water was provided *ad libitum*. On d 10, the water availability to 4 sheep in each chamber, chosen at random, was reduced to 50% of the mean daily intake recorded for each such individual between d 6 and d 9. This treatment then occupied a 3-d preliminary period (d 10, 11 and 12) and a 14-d period of data collection. Therefore, in total, this experiment was of 26 d duration.

FI, measured as DMI and OMI, was taken as the feed offered minus the feed refused. Total

urine and faeces collections were carried out for 5 days (d 16 to d 20). Urine was collected in acidified (H₂SO₄) containers, and output was measured at 08.00 h daily when the contents of the individual containers were made up to 2 litres. Subsamples of each (100 ml) were stored at -20°C for PD analysis using HPLC. Estimates of PD excretion were then used to estimate MNP as recommended by Chen and Gomes (1992).

Faeces was collected and weighed daily, and a 5% subsample was stored at -20°C for estimation of DM and OM contents. Apparent digestibilities of DM and OM were calculated from feed and faecal components.

Rumen fluid samples for VFA and NH₃ concentrations were taken on d 16, 19, and 22, at 12.00 h (3 h after feeding). VFA concentration in rumen fluid was measured by gas chromatography, and rumen NH₃ concentration was measured by an autoanalyser (Technicon; Sweden).

The frequency of primary rumen contractions was measured during a 15 min period of recording, 4 times a day, i.e. at 08.00 h (before feeding), 09.00 h (just after feeding), 14.00 h, and 17.00 h on 3 consecutive days (d 23, 24 and 25) by means of a pressure transducer fixed in the rumen (Riley, 1986). Only 8 transducers were available; each was shared between 2 sheep in each 30 min period of measurement. Within pairs of sheep, the one to be fitted first with the transducer was chosen at random during each measurement period.

The sensitivity of the available equipment was not calibrated, and it was thus not possible to compare the amplitude of the rumen contractions in sheep measured by different transducers. The contraction period was calculated as the mean length of the primary contractions observed during the four 15 min periods of recording on each animal, each day.

LOR was estimated by injecting a single dose (1.385 mg Cr/kg BW) of a Cr-EDTA complex as a soluble marker (Binnerts *et al.* 1968) into the rumen via the cannula. The injection was given at 09.00 h, at which time the previous day's feed residues were replaced with fresh material. In order to measure the amount of

Cr in the dose, the dose solution was diluted 500 times by volume, and the concentration of Cr in the diluted solution was measured by Atomic Absorption Spectrophotometer (AAS), and the total dose calculated as:

$$\text{Injected dose (mg)} = a \times 500 \times b$$

a = AAS reading

b = weight of dose (mg) injected

Rumen fluid samples (15 ml) were taken 3, 4, 5, 6, 8, 10, 12, 22, 23, and 24 h after injection of the marker. Samples were acidified with 4 drops of 95% H₂SO₄ and centrifuged at 3000 rpm for 10 min. The supernatant was removed and its concentration of Cr measured by AAS.

The concentration of Cr in the rumen fluid was related to time on a log-linear basis according to first order kinetics. A linear regression based on all samples was then developed: Log_e (μg/ml) on the Y-axis vs Time (min) on the X-axis. The relevant correlation and regression coefficients and the Y intercept (antilog) were then calculated and used to estimate:

$$\text{Rumen volume} = \frac{\text{Dose injected } (\mu\mu \text{ Cr})}{\text{Intercept } (\mu\mu \text{ Cr/ml})}$$

$$\text{LOR (ml/h)} = \text{Rumen volume (ml)} \times \text{slope} \times 60$$

Statistical analysis

The data were subjected to analysis of variance for a factorial structure within a completely randomised design. The sources of variance were temperature (2 levels), water availability (2 levels), and the interaction between these treatments. Since DMI and OMI are known to influence DMD and OMD respectively, covariate analyses were conducted to examine treatment effects on DMD and OMD after correction for differences in DMI and OMI.

Results and Discussion

The results of the current experiment are presented in Tables 1 and 2. There were no significant interactions (P>0.05) between temperature and water availability for any of the

parameters measured. The significant effects of ambient temperature were on WI, EMNP, rumen contraction period, RR and RT. WI in lambs watered *ad libitum* was significantly higher at 40°/32°C than at 20°C (4.5 vs 2.9 l/d). The EMNP at 40°/32°C was significantly (P<0.05) lower than that at 20°C (12.1 vs 19.0 g/kg DOMI). The rumen contraction period at 40°/32°C was longer (P<0.001) than at 20°C. The high temperature increased both RR (P<0.01) and RT (P<0.001). There were no significant effects (P>0.05) of temperature on the other parameters measured in this experiment.

WI restriction significantly (P<0.01) reduced DMI and significantly (P<0.05) increased DMD and OMD (Table 1). However, when DMI or OMI was used as a covariate, the differences in digestibility became non-significant (P>0.05). WI restriction also reduced rumen volume (P<0.001), LOR (P<0.001) and frequency of rumen primary contraction (P<0.05; Table 2). WI restriction significantly (P<0.05) increased the acetate concentration and the A:P ratio, but significantly (P<0.01) reduced acetate and propionate pools in the rumen (Table 2).

There were no significant (P>0.05) effects of watering regime on MNP, EMNP, rumen contraction period, RR, RT, and VFA and NH₃-N concentrations in the rumen (Table 2).

The lack of a difference in DMI between sheep at different temperatures (the means were coincidentally the same; Table 1) was unexpected and not in agreement with other experiments (e.g. Bhattacharya and Hussain, 1974; Koes and Pfander, 1975) that have shown that when the ambient temperature is increased, DMI is decreased. However, the current result is in agreement with the observations made by Rianto *et al.* (2001), in which it was found that DMI in sheep of this genotype did not decrease until ambient temperature reached 48°C, as long as drinking water was available *ad libitum*. The RH in both experiments was 40%. These findings confirm that for the Border Leicester x Merino sheep, ambient temperature did not cause any decrease in DMI until quite high levels of

Table 1. The Effects of Ambient Temperature and Watering Regime on Feed Intake and Digestibility, Estimated Net Microbial Nitrogen Production and Its Efficiency, Respiration Rate, and Rectal Temperature

Parameter	Ambient temperature		Watering regime		Effects ^b	
	20°C	40°/32°C	<i>Ad lib.</i>	50%	ANOVA	ANCOVA
WI (l/d) ^a	2.90	4.50	4.70	2.80	T** W**	-
DMI (g/d)	1150.00	1150.00	1360.00	940.00	W**	-
OMI (g/d)	1073.00	1073.00	1269.00	877.00	W**	-
DMD (%)	57.20	59.10	55.30	61.00	W*	ns
OMD (%)	59.30	58.70	57.10	60.90	W*	ns
MNP (g/d)	9.60	6.60	8.90	7.30	ns	-
EMNP (g/kg DOMI)	15.10	10.50	12.30	13.70	T*	-
RR (breaths/min)	70.00	161.00	115.00	116.00	T**	-
RT (°C)	39.40	39.70	39.50	39.60	T***	-

^a WI : water intake; DMI : dry matter intake; DMD : dry matter digestibility; OMD : organic matter digestibility; MNP : net microbial nitrogen production; EMNP : efficiency of net microbial nitrogen production; RR : respiration rate; RT : rectal temperature.

^b ANOVA : analysis of variance; ANCOVA : analysis of covariance; W : water; T : temperature; ns : P>0.05; * : P<0.05; ** : P<0.01; *** : P<0.001.

temperature (Rianto *et al.* 2001) were reached. However, the relatively high DMI in the current experiment presumably led to an increase in heat production, since both RR and RT were significantly (P<0.001) elevated at 40°/32°C (from 70 to 161 breaths/min for RR and from 39.4 to 39.7°C for RT).

The results showing a significant depressing effect of restricted WI on DMI is in agreement with the results of experiment by Rianto *et al.* (2002a), that when feed was given *ad libitum*, water restriction led to a decrease in DMI. The decrease in DMI in sheep under the restricted water regime may be attributed at least in part to the observed decrease in rumen motility. A decrease in rumen motility would be expected to have reduced the rate of passage of particulate digesta from the rumen and to have increased the MRT of particulate digesta, and thus reduced the rumen capacity to export particulate digesta per unit of time.

The significant differences between *ad*

libitum and restricted WI in DMD is also in agreement with the result of experiment by Rianto *et al.* (2002a), that when WI was restricted DMD was increased. However, when the statistical analysis took into account feed intake as a covariate, there was no significant difference in DMD between water regimes. It can be concluded that there was no evidence of direct effect of water restriction on digestibility, but that effect was an indirect one through decreased DMI.

The results for EMNP in the current experiment, showing higher values at 20°C than at 40°/32°C and a non-significant effect of WI, were not consistent with those of Rianto *et al.* (2001), which showed that EMNP at 50°/42°C (and a higher WI) was higher than that at 20°C (and a lower WI). A number of non-significant trends (Table 1) do, however, point to the possibility of the reduced EMNP having been a consequence of a reduction in MNP (6.6 g/d at 40°/32°C, compared to 9.6 g/d at 20°C).

Table 2. The effects of ambient temperature and watering regime on rumen volume, rumen liquid outflow rate, rumen motility, and volatile fatty acid and ammonia-nitrogen concentrations in the rumen

Parameter ²	Ambient temperature		Watering regime		s.e.m.	Effects ³
	20°C	40°/32°C	<i>Ad lib.</i>	50%		
Rumen Volume (l)	6.53	6.47	7.34	5.66	0.32	W***
LOR (ml/h)	510.00	461.00	664.00	307.00	43.00	W***
Rumen motility						
- Frequency (contractions/min)	1.30	1.20	1.30	1.10	0.05	W*
- Contraction period (seconds/contraction)	10.20	12.00	10.70	11.50	0.32	T***
VFA ²						
Total Concentration (mmol/l)	87.00	82.00	86.00	83.00	4.40	
- Acetate						
- Concentration (mmol/l)	62.50	57.90	60.20	60.10	0.60	
- molar %	71.80	70.60	70.00	72.40	0.71	W*
- pool (mmol)	408.10	374.60	441.90	340.20	40.25	W**
- Propionate						
- Concentration (mmol/l)	15.05	13.50	15.40	13.20	0.59	
- molar %	17.30	16.50	17.90	15.90	0.65	
- pool (mmol)	98.30	87.30	113.00	74.70	10.96	W**
- Acetate : Propionate (mol/mol)	4.20	4.30	3.90	4.60	0.20	W*
NH ₃ -N						
- Concentration (mg/l)	90.30	98.20	91.00	97.80	7.20	ns
- Pool (mg N)	590.00	635.00	668.00	554.00	46.80	W*

² LOR : liquid outflow rate; VFA : volatile fatty acid; NH₃-N : ammonia nitrogen.

³ W : water; T : temperature; ns : P>0.05; * : P<0.05; ** : P<0.01; *** : P<0.001.

Thus the reduced EMNP at 40°/32°C is consistent with the slightly lower VFA concentration (and thus lower microbial fermentation), and with a slightly lower LOR at this temperature, whereas mean DMI was identical at both temperatures.

In the current experiment LOR was not significantly affected by ambient temperature. This indicates that the extra water entering the rumen at 40°/32°C was absorbed through the rumen wall. Some of that water would be expected to have been evaporated during panting and sweating, and the remainder excreted in the urine. This LOR result is consistent with a non-significant effect of temperature on rumen

volume, and the fact that 40°/32°C treatment elevated WI to only 4.5 l/d; a much lower figure than the 7.5 l/d recorded at 50°/42°C (Rianto *et al.* 2001). It thus appears likely that failure of 40°/32°C to significantly increase LOR was a consequence of the fact that it induced only mild heat stress in these sheep (see also the increase of only 0.3°C in RT; Table 1).

The results showing that restriction of WI reduced LOR (from 664 to 307 ml/h; a reduction of 53 %) indicates that when sheep were given water *ad libitum*, more water flowed from the rumen into the lower digestive tract, and this would be expected to increase rumen 'wash out'

(Van Soest, 1994). Such an effect is consistent with the higher rumen volume and MNP under the *ad libitum* watering regimes.

The rumen motility results showed that high temperature increase the length of the contraction period but did not affect the frequency (Table 2). This is, at least partly, in agreement with findings of Attebery and Johnson (1969), which showed that high temperature decreased the amplitude of rumen contraction in cattle (amplitude was not measured in the current work), but did not influence the frequency of rumen motility.

That VFA concentration was not influenced by temperature is in agreement with the finding of Moose *et al.* (1969). It has been suggested that VFA concentration in the rumen is influenced by FI (Mishra *et al.* 1970; Van Soest, 1994) and is regulated by the balance between production and absorption rates (Van Soest, 1994). To that extent the current results are consistent: there were no significant effects of temperature on DMI in the current experiment. Total VFA concentration was not influenced by WI restriction. This VFA result suggests that there were no significant differences in microbial activity (Hungate, 1966) in the current work, an outcome that is consistent (Jaakkola and Huhtanen, 1993) with the non-significant difference observed in MNP.

Although the acetate and propionate concentrations were not significantly affected by watering regime, the pools of acetate and propionate were actually reduced, indicating that the amount of acetate and propionate available in the rumen at any one time was smaller under restricted than under *ad libitum* watering. This is consistent with the lower DMI recorded under restricted than under *ad libitum* watering. The absorption rate of VFA from the rumen was not measured in the current experiment, however it can be concluded that the total amount of VFA absorbed across the rumen wall was reduced under restricted watering (Leng, 1970). Acetate is converted to fatty acids and propionate is the main source of glucose in the rumen (Leng, 1970). The effect of watering regime

can be attributed to the higher molar % of acetate. This higher ratio indicates that a smaller proportion of VFA is available to be converted to glucose.

While Mishra *et al.* (1970) found that NH_3 concentration in the rumen was increased at high temperature, values in the current experiment were not significantly increased at 40°/32°C, though the trend was in that direction (Table 2). The lack of a significant difference in NH_3 concentration between temperatures in the current experiment can be attributed to the fact that the DMI, DMD and rumen volume at both temperatures were not significantly different. DMD in the ruminant is associated with the rate and extent of fermentation (Hungate, 1966), during which degradable dietary protein is converted into NH_3 (Leng (1970). Since NH_3 concentration is a dependent on the amount of NH_3 present and rumen volume, the non-significant differences between temperatures in DMD and rumen volume recorded in the current experiment would have been expected to have resulted in a non-significant differences in NH_3 concentrations. The previous discussion indicates that the 40°/32°C regime imposed led to only moderate level of heat stress. The likelihood thus remains that more stressful conditions, as frequently occur in the field, may indeed lead to increased ruminal NH_3 -N concentrations.

Reductions in rumen LOR would result in higher ruminal concentrations of NH_3 -N. Each of these individual effects was observed (Tables 1 and 2), but while the outcome for NH_3 -N concentration (an increase of from 91.0 to 97.8 mg/l) trended upwards, the effect was non-significant under the conditions of the current experiment.

Conclusions

From the current experiment, it can be concluded that:

1. At high temperature, a restricted watering regime resulted in a decrease in FI, compared with *ad libitum* regime. This may be attributed to the lower frequency of

rumen contraction.

2. Total VFA concentration was not affected by ambient temperature or watering regime, but acetate concentration and the A:P ratio were higher under the restricted watering regime than under the *ad libitum* conditions. Consequently, lambs on the restricted watering regime probably absorbed less propionate and therefore may have had a lower capacity to generate glucose for use in tissues.
3. The rumen NH₃ concentration was not affected by either temperature or water restriction.
4. EMNP was significantly lower at 40°/32°C than at 20°C, but was not affected by water restriction.

References

- Annison, E. F. and D. G. Armstrong. 1970. Volatile Fatty Acid Metabolism and Energy Supply. In *Physiology of Digestion and Metabolism in the Ruminant: Proc. 3rd Int. Symp.* Cambridge, August 1969, pp 422-437 (A. T. Phillipson, E.F. Annison, D. G. Armstrong, C. C. Balch, R.S. Comline, R. N. Hardy, P. N. Hobson and R. D. Keynes, Eds.). Oriel Press, Newcastle-upon-Tyne.
- Attebery, J. T. and H. D. Johnson. 1969. Effects of Environmental Temperature, Controlled Feeding and Fasting on Rumen Motility. *J. Anim. Sci.* 29: 734-737.
- Bhattacharya, A. N. and F. Hussain. 1974. Intake and Utilization of Nutrients in Sheep Fed Different Levels of Roughage Under Heat Stress. *J. Anim. Sci.* 38: 877-886.
- Binnerts, W. T., A. T. Van't Kloosterand, and A. M. Frens. 1968. Soluble Chromium Indicator Measured by Atomic Absorption in Digestion Experiments. *Vet. Rec.* 82: 470.
- Blaxter, K. L. 1962. *The Energy Metabolism of Ruminants.* Hutchinson, London.
- Chen, X. B. and M. J. Gomes. 1992. Estimation of Microbial Protein Supply to Sheep and Cattle Based on Urinary Excretion of Purine Derivatives - an Overview of the Technical Details. International Feed Resources Unit, Occasional Publication, Rowett Research Institute, Aberdeen.
- Gengler, W. R., F. A. Martz., H. D. Johnson, G. F. Krause, and L. Hahn. 1970. Effect of Temperature on Food and Water Intake and Rumen Fermentation. *J. Dairy Sci.* 53: 434-437.
- Hungate, R. E. 1966. *The Rumen and Its Microbes.* Academic Press, New York.
- Jaakkola, S. and P. Huhtanen. 1993. The Effects of Forage Preservation Method and Proportion of Concentrate on Nitrogen Digestion and Rumen Fermentation in Cattle. *Grass and Forage Sci.* 48: 146-154.
- Kelley, R. O., F. A. Martz, and H. D. Johnson. 1967. Effect of Environmental Temperature on Ruminant Volatile Fatty acid Levels with Controlled Feed Intake. *J. Dairy Sci.* 50: 531-533.
- Kennedy, P. M., R. J. Christophersonand, and L. P. Milligan. 1976. The Effect of Cold Exposure of Sheep on Digestion, Rumen Turnover Time and Efficiency of Microbial Synthesis. *Br. J. Nutr.* 36: 231-242.
- Koes, R. M. and W. H. Pfander. 1975. Heat Load and Supplement Effects on Performance and Nutrient Utilization by Lambs Fed Orchard-Grass Yay. *J. Anim. Sci.* 40: 313-319.
- Leng, R. A. 1970. Formation and Production of Volatile Fatty Acids in the Rumen. In *Digestion and Metabolism in the Ruminant: Proc. 3rd Int. Symp.* Cambridge, August 1969, pp. 406-421 (A.T. Phillipson, E.F. Annison, D.G. Armstrong, C.C. Balch, R.S. Comline, R.N. Hardy, P.N. Hobson and R.D. Keynes, Eds.). Oriel Press, Newcastle-upon-Tyne.
- Leng, R. A. 1990. Factors Affecting the Utilization of 'Poor quality' Forages by Ruminants Particularly Under Tropical conditions. *Nutr. Res. Rev.* 3: 277-303.
- Mishra, M., F. A. Martz, R. W. Stanley, H. D. Johnson, J. R. Campbell, and E. Hilderbrand. 1970. Effect of Diet and

- Ambient Temperature-Humidity on Ruminant pH, Oxidation Reduction Potential, Ammonia, and Lactic Acid in Lactating Cows. *J. Anim. Sci.* 30: 1023-1028.
- Moose, M., C. V. Ross, and W. H. Pfander. 1969. Nutritional and Environmental Relationships with Lambs. *J. Anim. Sci.* 29: 619-627.
- Mount, L. E. 1979. *Adaptation to Thermal Environment*. Edward Arnold, London.
- NRC. 1981. *Effect of Environment on Nutrient Requirements of Domestic Animals*. National Academic Press, Washington, D.C.
- Rianto, E., M. K. Hill, and J. V. Nolan. 1998. The Effect of Diet Quality on Feed Intake, Feed Digestibility and Growth Rate of Lambs at Ambient Temperature of 20 and 30°C (*Bulletin of Animal Science, Suppl.* Ed. October 1998: 216-222).
- Rianto, E., C. J. Thwaites, and J. V. Nolan. 2001. The Effects of High Ambient Temperature and Urea Supplementation on Feed Digestibility and Microbial Protein Production in Lambs. *J. Trop. Anim. Sci. Special Edition* October: 58-67.
- Rianto, E., C. J. Thwaites, and J. V. Nolan. 2002a. The Effects of Water Restriction at Elevated Ambient Temperature on Feed Intake and Digestibility, and Microbial Nitrogen Production in Lambs Fed Wheaten chaff. *J. Trop. Anim. Sci.* 27: 83-87.
- Rianto, E., C. J. Thwaites, and J. V. Nolan. 2002b. Feed Digestibility and Microbial Nitrogen Production in Pair-Fed Lambs at 20°C and 50°/42°C When Water Intake was Restricted at the Higher Temperature. In *Animal Production and Total Management of Local Resources. Proc. 3rd International Seminar on Tropical Animal Production, held in Yogyakarta, 15-16 October, 2002.* pp. 71-76.
- Riley, J. L. 1986. A Radio Telemetry Capsule and Demodulator for Recording Rumen Motility. *Cornell Vet.* 76: 348-353.
- Van Soest, P. J. 1994. *Nutritional Ecology of the Ruminant, 2nd Ed.* Cornell University Press, Ithaca.
- Weldy, J. R., R. E. McDowell, P. J. Van Soest, and J. Bond. 1964. Influence of Heat Stress on Rumen acid Levels and Some Blood Constituents in Cattle. *J. Anim. Sci.* 23: 147-152.
- Winugroho, M., D. Sastradipradja, and B. A. Young. 1990. Adaptation of Small Ruminants to Tropical Indonesia. In *Goat and Sheep Production in Indonesia*, pp. 78-118 (M. Wodzicka-Tomaszewska, S. Gardiner, A. Djajanegara and T.R. Wiradarya, Eds.). IPB-Australia Project and Gramedia, Jakarta.