UNIVERSITY OF ALBERTA

ENERGY AND PROTEIN UTILISATION BY MALAYSIAN CATTLE AND BUFFALO

by

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Audrey Rode
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Dear Audrey

Re: PhD Thesis - J.-B. Liang

I have received a fax from Mr J.-B. Liang asking that I notify you concerning use of material in his PhD thesis that has been submitted to a scientific journal for publication. I am uncertain as to exactly what is being asked and if this letter is unclear or insufficient would you please contact me.

Mr Liang's studies were designed to be published in scientific journals. The fact that they have been submitted is an indication of success in this respect. My name appears on the paper because I was his primary supervisor and his collaborator during the research phase of his studies. His studies were however conducted in Malaysia and with him fully in charge of the projects. My input was primarily in the planning stage and subsequently through letters and faxes. I visited the project site for short periods on two occasions.

I am proud to be included as an author on Mr Liang's papers and I fully support and believe it is appropriate for him to include the submitted papers in his PhD thesis.

Yours faithfully

B.A. YOUNG
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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled ENERGY AND PROTEIN UTILISATION BY MALAYSIAN CATTLE AND BUFFALO in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Animal Nutrition.

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ABSTRACT

Two feeding trials involving 32 cattle and 32 buffaloes of 137 to 149 kg body weight (BW) and 103 to 150 kg BW, respectively were conducted over a period of 14 months in Malaysia. In the first trial, maintenance requirements and efficiencies of energy use for tissue storage in Kedah-Kelantan (KK) cattle (*Bos indicus*) and swamp buffalo (SB) (*Bubalus bubalis*) were measured in a double 4x4 latin square trial, replicated four times for each species. The animals were fed on palm kernel cake at maintenance (M), 1.4M, 1.8M and *ad libitum* intakes. Retained energy (RE) was estimated for each animal from the difference between initial and final body fat and protein compositions for each period using the tritiated water dilution procedure. Energy maintenance requirement for KK (335 kJ ME $kg^{-0.75}$ BW) was ($p<0.05$) than that for SB (313 kJ ME $kg^{-0.75}$ BW). Efficiencies for maintenance and RE for KK (0.64 and 0.30, respectively) were higher ($p<0.05$) than for SB (0.48 and 0.25, respectively). Microbial N yield per kg digestible DM intake, predicted using urinary allantoin excretion for KK (18.4 g) was higher ($p<0.01$) than for SB (10.4 g), but net N depositions were not significantly different between the two species. The second trial examined differences between two breeds of cattle (KK and Sahiwal x Friesian crossbred, SF) and two breeds of buffalo (SB and Murrah buffalo MB) fed at 700 kJ ME $kg^{-0.75}$ BW and *ad libitum* intake levels. Efficiency for RE was higher ($p<0.05$) for beef breeds (averaged 0.20) than for dairy breeds (averaged 0.17). *Ad libitum* food intake (kJ ME $kg^{-0.75}$ BW per day) was highest for SF (905), followed by MB and KK (averaged 850) and SB (701). The Maximal RE for the corresponding intakes were 141, 115, 135 and 118 kJ $kg^{-0.75}$ BW per

day. However, RE (kJ kg$^{-0.75}$ BW per day) at a standardised intake level of 700 kJ ME kg$^{-0.75}$ BW per day was highest for SB (118), followed by SF (105), KK (102) and MB (89).

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I. INTRODUCTION

Until very recently, cattle and swamp buffalo in Malaysia were kept mainly to cultivate paddy and to date, the bulk of the cattle and buffalo are still owned by the traditional farmers in the villages. The number of animals owned by each farmer ranges from one to 50 head, which usually is indicative of the social and economic status of the owner. Unproductive and extra animals are slaughtered for meat for local consumption or sold for cash. In recent years increasing demand for meat has stimulated a move to rear cattle and buffalo in commercial or semi-commercial enterprises. The move is away from the traditional production system of leaving the cattle and buffalo to stray-graze on forages available around the villages towards more economically-viable, intensive systems.

Nutrition is a major input in commercial animal production and in many instances the dominant economic factor which determines the success or failure of a particular livestock enterprise. Knowledge of the nutritional requirements of the animals is needed so that feed resources can be efficiently used to optimize output. Information on the efficiency of nutrient utilization of ruminant species in the Malaysian environment is lacking. The recommendations on nutrient requirements for cattle by the Agricultural Research Council (ARC) of UK and the National Research Council (NRC) of the USA are commonly referred to by Malaysian workers when developing feeding programmes. The choice of system arises from convenience or familiarity due to the users' previous training in the respective country. There has been little scientific evaluation of whether either of these nutrient requirement systems is suitable for Malaysia.

Recommendations by ARC and NRC were mainly based on research from temperate countries using feeds and breeds of animals not commonly found in the tropics. Because breed, age, sex and environment affect growth rate, feed conversion efficiency and carcass composition, these factors also influence nutrient requirements. Therefore, the relevance of information derived from temperate countries to the humid tropical environment in Malaysia needs to be examined.

The purpose of this thesis is to quantify dietary energy and protein requirements of indigenous cattle and buffalo in Malaysia. The results of the study will provide additional information for the development of feeding standards for the local cattle and buffalo currently being undertaken by the Malaysian Agricultural Research and Development Institute (MARDI).

CATTLE AND WATER BUFFALO OF MALAYSIA

Population Statistics

Ruminant production has played a minor role in Malaysia, contributing only 6.3% of the total value of livestock products (D.V.S., 1989). As a result of the government's support for higher local production of milk and meat (beef), the cattle population has increased from 301,200 head in 1970 to 614,498 head in 1990 (D.V.S., 1991). Water buffalo in Malaysia are mainly the swamp type and were the main source of draught power in paddy cropping two to three decades ago. Modern machinery has gradually replaced the traditional animal function resulting in a continuous decline in the buffalo population from 233,040 head in 1970 to 129,817 in 1990 (D.V.S., 1991).

Animal Types

Kedah Kelantan (KK) cattle (*Bos indicus*) are the indigenous cattle of Malaysia. This breed is believed to have evolved from the humped Chinese Yellow cattle from Southern China. It is a well-adapted small tropical breed with a mean birth weight of 15.6 kg and mature weight of about 280 kg (Devendra et al., 1973).

The swamp buffalo (*Bubalus bubalis*) in Malaysia are genetically similar to those found in many other countries of South East Asia. Buffalo are behaviourally well-adapted to the wet tropics, and prefer to wallow in swamps to keep cool. The mean birth weight of swamp buffalo is 30 kg (Ahmad, 1983; Liang et al., 1991) and they have a mature weight of about 540 kg (Ahamd, 1981).

The Local Indian Dairy (LID) cattle (*Bos inducus*) and the Murrah buffalo (*Bubalus bubalis*) which form the base population of dairy animals in Malaysia are believed to have been brought in by early immigrants from India and Pakistan. Currently the dairy industry is dominated by the Indian community operating family farms in the suburbs where their products are easily marketed in the adjacent cities. Recent government policy to increase local milk production is creating a new group of dairy farmers in this country, using mainly Sahiwal x Friesian crossbreds imported from New Zealand and Australia, which are believed to be more productive than the LID cattle and Murrah buffalo. Organised marketing systems consisting of a network of milk collecting centers are established with government assistance to collect and market the dairy produce.

Draught Animals

The boxy hooves and very flexible pastern and fetlock joints of the swamp buffalo allow these animal to work efficiently in paddy fields (Anon, 1984). However, this use of buffalo in paddy cultivation in Malaysia had been largely replaced by the internal combustion engine. Concurrent with the decrease in use of buffalo in the paddy field has been a rapid increase in the oil palm industry in Malaysia and development of a serious shortage of human labour in the oil palm plantations. Several plantations are now using buffalo to assist with the transportation of fruit bunches within the plantation. Productivity and income of buffalo-assisted oil palm fruit harvesters were reported to be 30% greater than for those using the traditional high man-power basket method (Muirhead, 1980; Liang and Rahman, 1985).

Working buffalo can gain 0.3 to 0.6 kg d^{-1} while grazing on forages under oil palm plantations. These growth rates are comparable to values reported for buffalo grazing under open pasture conditions. Other advantages of using draught buffalo in the oil palm plantations include a saving in weeding costs and a lower rate of labour turnover (Liang and Rahman, 1985).

DIFFERENCES BETWEEN CATTLE AND WATER BUFFALO

There have been numerous comparative studies of the physiology and nutrition of cattle and buffalo (Ichhponani et al., 1962; Ichhponani and Sidhu., 1965; Johnson et al., 1967; Chutikul, 1975; Devendra, 1985; Abdullah et al., 1986; Liang and Samiyah, 1988; Pradhan, 1989; Kennedy et al., 1992) and comprehensive reviews have been prepared (Devendra, 1987; Wanapat, 1989; Pradhan, 1992). The following sections emphasize information from Malaysia and, when necessary from other countries, particularly neighbouring ones which share similar types of animals and environments.

Productivity and Constraints

The Malaysian KK cattle breed is well known for its high fertility under both village and farm conditions. Annual calving percentages of near 100% have been reported on commercial farms (Ng, 1987). They are generally slow growing, i.e., normally no more than 0.3 kg d^{-1} while grazing under village conditions (Devendra et al., 1973). However, high average growth rate of 0.6 kg d^{-1} were reported when KK cattle were fed high quality diet based on agro-industrial by-products in feedlots (Shamsudin et al., 1987).

Swamp buffalo tend to be less fertile than KK cattle, producing on average only two calves every three years. Postpartum anoestrus is a major constraint to their fertility (Jainudeen and Sharifuddin, 1987). Irregular calvings are associated with seasonal conditions and linked with poor quality or low availability of feed (Liang, 1987; Nordin and Jainudeen, 1993). Gestation length of swamp buffalo averages 330 days and is about a month longer than KK cattle (Liang et al., 1991). The growth potential of swamp buffalo is similar to that of KK cattle, both species gaining up to about 0.6 kg d^{-1} when fed high energy tropical feedstuffs (Sukri, et al 1987; Shamsudin et al, 1987).

Milk production potential of the indigenous KK cattle is 2.5 to 3.5 kg d^{-1} with 4.2% fat content (Devendra et al., 1973; Lee et al., 1978) and for swamp buffalo, 3.4 kg d^{-1} (Liang et al., 1980). Milk yield for the various breeds of cattle in Malaysia (LID, Friesian x LID, and Sahiwal x Friesian crossbreds) ranged between 4.8 to 10.8 kg d^{-1} depending on the amount of concentrate supplementation (Sivarajasigam et al., 1986; Wong et al., 1987). Average milk production of Murrah buffalo during the second to fourth month of lactation was reported to be about 9.4 kg d^{-1} with a fat content of 6% (Liang et al., 1992).

Digestion and Physiological Differences

Buffalo are claimed to use poor quality diets better than cattle. There are sufficient independent data to indicate that degradation rates of feed material in nylon bags incubated in the rumen of buffalo are faster than in cattle (Ichhponani et al., 1962; Abdullah et al., 1986; Liang and Samiyah, 1988). Higher rates of volatile fatty acids (VFA) production were measured in swamp buffalo than KK cattle fed on chopped guinea grass (Abdullah et al., 1986) and rice straw diet (Abdullah et al., 1991), suggesting that the rate of rumen fermentation in buffalo is generally higher than in cattle. In contrast, Fujihara et al. (1991) measured higher rates of VFA production in KK cattle than swamp buffalo fed a diet consisting of tropical grass supplemented with palm kernel cake pellets. Some uncertainty exists as to the cause of the apparently contradiction in the data.

In vivo digestibility studies did not show a clear advantages of buffalo over cattle in rate of digestion. Moran et al. (1979) reported that there were few differences between breeds of cattle and buffalo in their ability to digest and utilise low quality roughage when comparisons were adjusted to similar live-weight and feed intake. Similar results were reported by Liang and Samiyah, (1988) who found that rates of degradation of 4-week and 10-week old guinea grass in nylon bags incubated in rumen of buffalo were higher than in cattle. However, these workers did not detect any difference in *in vivo* digestibility between the two species (Table 1).

The inconsistency of nylon-bag and *in vivo* studies could be due to interactions between digestibility and other physiological factors including intake, rumen microbial composition and rate of passage of digesta, which have known effects on digestion. However, results from the literature regarding the measurement of these parameters were variable. A study by Liang and Samiyah, (1988) (data presented in Table I.1) showed that dry matter intake per metabolic weight ($kg^{-0.75}$ BW) was affected by diet quality. No significant difference was found between cattle and buffalo fed 4-week old guinea grass, but buffalo exhibited higher intake than cattle when 10-week old guinea grass was offered to the same animals. Also the retention of rumen digesta was longer for buffalo than cattle fed 4-week old guinea grass. Retention time remained unchanged for buffalo while that of cattle increased to a level similar to buffalo when the same animals were offered 10-week old guinea grass. On the other hand, Kennedy et al., (1992) found unconsistent differences in voluntary intakes of rice straw diets between swamp buffalo and *Bos taurus x Bos indicus* crossbred cattle but buffalo had faster outflow rates of microbes and small digesta particles from the rumen.

Kennedy et al., (1992) also reported a lower content of microbes in ruminal dry matter in buffalo than cattle but this did not depress the rate of digestion in situ. They suggested that rate of digestion may have been maintained by a greater proportion of fibrolytic microbes in swamp buffalo. Similarly, the rumen ciliate protozoa population was lower in swamp buffalo than KK cattle fed with chopped guinea grass and rice straw (Imai et al., 1992), and this may lead to higher yields of bacterial protein from the rumen (Bird, 1991). It is difficult to identify clear differences between cattle and buffalo in some of these digestive parameters. However, contradictary results could be due to differences in scientific procedures, diet and type of animal used in the various studies.

Energetic and Nitrogen Efficiencies

Several experiments have examined energy requirements for maintenance and efficiencies for gain for cattle and buffalo under Malaysian conditions. Generally, maintenance requirements of cattle have been found to be higher than for buffalo (Devendra, 1981; Devendra and Wan Zahari, 1981; Liang, 1987 and Liang et al., 1988), but diet quality is known to affect maintenance metabolism (Liang et al., 1991).

It is difficult to make comparisions in energetic efficiency for gain between cattle and buffalo from the presently available data because of varied experimental conditions. However, acceptable comparisons can be made using the data of Liang and Samiyah (1989) and Liang et al. (1992), because the two experiments used a similar diet. Those results althought not statistically compared, showed that swamp buffalo are more efficient for weight gain than Murrah buffalo (a dairy type), and buffalo are generally more efficient than cattle. However, Mudgal (1988) reported that crossbred cattle (Brown

Swiss x Sahiwal) utilized metabolisable energy for milk production more efficiently than Murrah buffalo under Indian conditions.

Kennedy et al. (1992) reported than buffalo recycled 50% more urea into the rumen than cattle, and more microbial nitrogen left the abomasum of buffalo than cattle, which suggest more efficient use of nitrogen by buffalo. Devendra (1985) reported that because of lower urinary nitrogen output, nitrogen retention in swamp buffalo was higher than KK cattle. However, the maintenance requirement for digestible crude protein was found to be higher in swamp buffalo (Devendra, 1984a) than KK cattle (Devendra, 1984b) in Malaysia.

FEEDING SYSTEMS

Energy based systems of the Agriculture Research Council (ARC) of the UK, and the National Research Council (NRC) of the USA are widely used in developing countries. The choice arises from convenience and familarity. And there has been little scientific evaluation to find out which of these systems are suitable for the humid tropics. Preston and Leng (1987) suggested that the conventional systems fail to account for needs for specific nutrients, such as glucose, of animals feeding on tropical forages or on agro-industrial by-products, the fermentation of which gives rise to relatively low production of propionic acid. A brief review of the various feeding system follows.

Metabolisable Energy System

The metabolisable energy (ME) system of ARC (1965, 1980) was devised by the late Sir Kenneth Blaxter and co-workers from UK. Basically, the metabolisable energy system provides a set of rules which link tables of feed composition to tables listing the energy requirements of animals. The earlier ARC (1965) recommendations were later modified (ARC, 1980) by incorporating up-to-date data.

The metabolisable energy system assumed that, below energy maintenance, increments of metabolisable energy of a particular diet are used with a constant efficiency in promoting energy retention. Another, lower, efficiency value was used for production (growth, activity, lactation and pregnancy) and applicable above maintenance levels of feeding. Thus the total animal requirement is the sum of the requirements for maintenance plus production, where in the ARC system the efficiencies of use of energy for these functions were based on calorimetric measurement on fasted and test animals fed at pre-determined levels. The metabolisable energy system of ARC was simplified for practical use in a publication by the Ministry of Agriculture, Fisheries and Food, UK (MAFF, 1975). This modified ARC system has been widely adopted throughout the world.

Net Energy System

The California net energy (NE) system for cattle was initially developed by Lofgreen and Garrett (1968). Basically, the net energy system for growing and finishing beef cattle assigns two net energy values to each feedstuff and matches them with animal requirements. The net energy available or required for maintenance is termed NE_m, and net energy available or required for growth is termed NE_g. For beef cattle it was adopted in 1976 by the National Research Council of USA (NRC, 1976), and later the effects of sex and breed of cattle were incorporated into the system (NRC, 1984).

Japanese Feeding Standards

The Japanese feeding standards for beef cattle (1987) and dairy cattle (1987) are based on concepts similar to the NRC's, but incorporate data derived locally. In the Japanese system energy values in animal requirements and feed tables were expressed as digestible energy and total digestible nutrient (TDN) with the intention of updating those values to metabolisable and net energy values in future.

Australian Feeding Standards

The Australian feeding standards (1990) have strong emphasis on energy expenditure for activities required for grazing and for the effects of the extreme climatic conditions in Australian. Because of the Australian environment, and extensive system of animal production in Australia their system may be more relevant to Malaysia's needs than the other systems.

Protein Systems

The most widely used method for expressing the ruminant's requirement for protein and the extent to which feeds could meet these requirements is based on digestible crude protein. Since this method was considered to give too much weight to non-protein nitrogen, systems including protein equivalent and available protein were later developed (ARC, 1965). The ARC protein system was improved to consider separately the nitrogen requirements of the microbial population and the host animal. Rumen degraded nitrogen (RDN) required by the microorganism and undegraded dietary nitrogen (UDN) requirement were the two terms used by ARC (1980). Alderman (1992) summarised further development of the ARC approach which is now referred to as the Metabolisable Protein System. In this approach, "Metabolisable protein" is microbial crude (MCP) plus digestible undegraded dietary protein (DUP) and the earlier used terms of RDN and UDN are no longer used.

Feeding Standards for Developing Countries

Realising the need of feeding standards for farm animals in the developing countries, Kearl (1982) published feeding standards for ruminants in developing countries. Feedstuffs, including agro-industrial by-products commonly used as feeds for ruminants in many developing countries, were included in its tables of feed composition. Another useful feature was that some species which are important in the developing countries, such as buffalo and goat, were considered for the first time. However, because research data from the humid tropics were not extensively used by Kearl (1982), there could limit the potential usefulness of this system in South East Asian countries, including Malaysia.

System Simulation

System simulation has been introduced into the field of animal science since 1960s. Arcus (1963) was among the first to foresee the potential of using simulation models to study grazing management. With the rapid advance in computer facilities in the last two decades, a systems approach, using mathematical models and simulation, has developed at a remarkable pace (Oltjen, 1987).

Initially, most ruminant models were for animal and forage production systems (Jones, 1968; Trebeck, 1972). Since then many beef cattle production models have been developed at an individual animal level (Khan and Spedding, 1983, 1984; Oltjen et al., 1986; Walker et al., 1988; Keele et al., 1992; Williams et al., 1992). Many of the published simulation models were empirical rather than mechanistic. The mechanistic models by Baldwin and colleagues simulating animal energetics (Baldwin and Smith, 1971a) and intermediate metabolites (Baldwin and Smith, 1971b) were pioneers in this field.

In Malaysia, Dahlan (1989) developed a model to simulate forage yields and cattle production under oil palm plantations. He has, for example, estimated that Malaysia could double its present cattle population (about half a million) by integrating cattle rearing in the existing oil palm plantations.

RESEARCH NEEDS

There is a need to develop feeding standards based on animal and feed data collected in their normal environment to provide guidelines for feeding of animals in the tropics. Existing feeding standards and systems models which are based on information from temperate countries temporarily serve as useful references for the tropics. Kearl's (1982) attempt to develop feeding standards for various species of animals for developing countries is useful but needs substantial refinement. Kearl included values for species such as buffalo, which had never been included in previous feeding systems. However, the suggested values for buffalo were based mainly on experiment data from the dairy breeds in the Indian sub-continent. The bulk of buffalo in the humid tropics of South East Asia, including Malaysia, are of the swamp type. Direct application of the suggested values by Kearl (1982), needs careful interpretation since swamp buffalo and dairy buffalo differ significantly in many aspects (Bongso et al., 1984; Liang et al., 1991).

The Malaysian Agricultural Research and Development Institute (MARDI) recently initiated a programme to develop feeding standards for farm animals in the humid tropics in general and in Malaysia in particular. Initial information on cattle and swamp buffalo based on empirical experiments conducted by Devendra and co-workers (Devendra, 1981; Devendra and Zahari, 1981; Devendra, 1984a, 1984b) and more recently by Liang and co-workers (Liang et al, 1988; Liang and Samiyah, 1989; Liang et al, 1991; Liang et al, 1992) together with computer simulation models developed by Dahlan (1989) are proving the success of the programme. However, there is a need to validate some of the earlier data using more up-to-date techniques and experimental procedures. For instance, studies of energy requirements should be based on energy balance rather than on body weight change alone as used earlier. Also the Metabolisable Protein System (Alderman, 1992) should be considered. To benefit the different animal production systems in Malaysia, advancement in simulation modelling techniques using computers must be exploited to generate useful information which is too expensive and time-consuming to develope by empirical experimentation.

OBJECTIVES OF THESIS

The main aim of this thesis is to provide research data to complement the data base for the development of feeding standards for cattle and buffalo in Malaysia. The following objectives were set to achieve the above aim:

1) To quantify energy maintenance requirements and energetic efficiencies of fat and protein storage in Malaysian cattle and buffalo.

2) To examine efficiencies of nitrogen use by Malaysian cattle and buffalo.

3)To develop practical computer models for feeding standards in Malaysia.

To achieve the above objectives, two feeding trials involving a total of 32 cattle and 32 buffaloes were conducted in MARDI Serdang Station from September 1991 to November 1992. In the first feeding trial, efficiencies of dietary energy and protein utilisation by growing KK cattle and swamp buffalo were quantified (Chapter II). Microbial nitrogen yields of the same cattle and buffalo were estimated using urinary allantoin excretion to assess their contributions to net nitrogen retention in the two species (Chapter III).

The second feeding trial (eight animals per breed) (Chapter IV) compared the energetic efficiencies of two sexes of two breeds of cattle (KK and Sahiwal x Friesian crossbred) and two breeds of buffalo (swamp and dairy). Finally, Chapter V integrates the material contained in Chapters II to IV and develops dynamic computer-based feeding standards for buffalo production under Malaysian conditions.

Table I.1 Voluntary intake and digestive characteristics of swamp buffalo and Brahman heifers given guinea grass cut at two stages of growth (Liang and Samiyah, 1988)

Parameter	4-wk old gras		10-wk old grass	
	Buffalo (N=8)	Cattle (N=8)	Buffalo (N=8)	Cattle (N=8)
Liveweight (kg)	279[a]	225[b]	278[a]	219[b]
DM intake (kg)	6.0[a]	4.6[c]	5.1[b]	4.1[d]
DM intake/kg$^{0.75}$ (g)	88.6[a]	79.7[ab]	74.8b	64.7[c]
DM digestibility (%)	65.7[a]	65.8[a]	52.8[b]	52.3[b]
DM retention:				
Outflow rate, K (%/h)	2.4[b]	3.2[a]	2.1[b]	2.3[b]
Half-Time (h)	46[a]	31[b]	47[a]	44[a]
DM degradability in nylon bag:				
24 h (%)	41.0[a]	31.0[b]	25.2[c]	20.4[d]
48 h (%)	48.8[a]	45.2[b]	33.0[c]	29.9[d]

a,b,c,d = Values in the same row not followed by a common letter differ significantly ($p<0.05$)

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II. COMPARATIVE ENERGETIC EFFICIENCIES OF KEDAH-KELANTAN CATTLE AND SWAMP BUFFALO

INTRODUCTION

Feed resources for ruminants in the humid tropical countries, such as Malaysia, are usually scarce and of poor quality. There are also apparent differences between temperate *Bos taurus* and the tropical *Bos indicus* breeds of cattle and of indigenous types. Greater understanding of the efficiency of feed utilization by locally available animals is needed so that the limited available resources can be used with maximum efficiency.

Meat production efficiency depends on many factors, including nutrient requirements of animals for maintenance and efficiency of deposition of body tissues (ARC, 1980). Solis et al. (1988) reported that metabolisable energy (ME) requirement for maintenance of cows of different breed types (*Bos taurus, Bos indicus* and their crosses) differed as much as 40% while efficiency of ME used for tissue deposition differed up to 100%. Similar findings were also found for cattle under Malaysian conditions (Liang et al., 1988).

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The present experiment was designed to quantify maintenance requirements and to measure energetic efficiencies of tissue storage in the Malaysian Kedah Kelantan (KK) cattle (*Bos indicus*) and swamp buffalo (*Bubalus bubalis*). The main objective was to examine whether the two species, which are the main meat source (beef) in Malaysia, differ in their efficiencies of feed utilization.

MATERIALS AND METHODS

Animals and Diet

The experiment was conducted at the Malaysian Agricultural Research and Development Institute's Research Station, Serdang from October 1991 to September 1992. Sixteen entire male KK cattle with an initial body weight (BW) of 149.2 ± 16.9 kg and an equal number of male buffaloes (initial weight of 137.3 ± 21.5 kg) were used. All animals were purchased from commercial farms approximately 1 month before the trial. The experimental diet consisted of solvent extracted palm oil kernel cake pellets (Table II.1). During a pre-experimental period of 1 month, the animals were fed at 1.5 maintenance requirement (assuming M = 425 kJ ME $kg^{-0.75}$ BW per day) established earlier for KK cattle (Liang et al., 1991).

Experimental Design

The experiment consisted of a double 4X4 latin square experiment, replicated four times for each species. A total of 32 animals commenced the trial. The experiment consisted of four 70-day feeding periods and four feeding treatment levels (M, 1.4M, 1.8M and *ad libitum* feed offering). Each animal was assigned to treatment levels so that four animals per species were fed at each treatment level during each period. Treatment levels were rotated for each animals following a predetermined sequence in a manner such that each animal underwent all the four treatments during the experiment.

Intake and Body Weight

The animals were housed in individual stalls of 1.2 x 2.5 meter each. Feed was weighed daily and offered at 0900 h to each animal after the removal of feed residuals from the previous day. The difference between the amount of feed offered and the residue removed was taken as the amount consumed. Feed spillage and losses were minimal (< 2% of feed offered). Daily feed intake data were pooled and averaged over each week. Clean water and mineral blocks (containing on per kg basis, 380 g of sodium, 5 g of magnesium, 1.5 g of iron, 300 mg each of zinc and copper, 200 mg of manganese, 150 mg of iodine, 50 mg of cobalt and 10 mg of selenium) were available at all times. Vitamin supplements (containing 800,000 i.u. vitamin A, 400,000 i.u. vitamin D_3 and 200 mg vitamin E), were given intra-muscularly to all animals at the beginning of each period.

Animals were weighed weekly (Wednesdays) in the morning (0830) before daily feeding. On the day prior to weighing, unconsumed feed and water were removed at 1500 h. The new weight of each animal was used as the basis to calculate the daily feed allocation for the following seven days. The weekly weights of each animal for each period were regressed against time using rectilinear regression;

Weight = a + b day ....(1)

The intercept (a) was taken as the adjusted initial weight and the slope (b), the average daily gain (ADG) for the 70-d period. Adjusted final weight for each period was calculated using equation 1 for each animal.

Body Composition and Retained Energy

The initial and final body compositions for each animal for each feeding period were estimated using tritiated water (TOH) dilution technique following Little and McLean (1981). At the time of administration of TOH (1500 h), the animals were deprived of food and water untill the second blood samples were collected the next morning. A jugular blood sample was drawn from each animal using a vacutainer immediately before the TOH injection to determine the background activity of tritium. A second blood sample was obtained via the jugular vein at 0900 h the morning after the TOH injection. Determinations of initial and final body compositions were measured together with the weekly weighing, i.e., blood samples for background count and TOH injection were done on Tuesday afternoon and blood samples were taken when the animals were weighed on Wednesday morning. Duplicate 200 mg plasma samples were weighed and transferred to a scintillation vial and counted in 15 ml of scintillation fluid (Beckman Safe, Beckman, U.S.A.) using a counter (Beckman model LS6000IC). Diluted TOH injectate was counted under identical conditions. TOH space, calculated as the volume into which the injected TOH apparently had diluted, was used to estimate total body water (TBW). Total body fat (TBF) and total body protein (TBP) of individual animal were estimated using equations of Little and McLean (1981).

Four weeks after the end of the feeding trial, eight cattle and seven buffaloes were sacrificed and physically dissected to determine fat and protein contents by weight. The fat and protein data obtained from the physical dissection were compared with those predicted using the indirect TOH dilution procedure to examine the reliability of the latter procedure.

Retained energy (RE) of individual animals was determined for each period from the change from the initial to final total body fat and protein, based on the adjusted initial and final weights and assumed calorific value of 39.3 kJ g^{-1} and 23.6 kJ g^{-1} for fat and protein, respectively (Garrett and Hinman 1969).

Digestibility Trials

Diet digestibility was determined for each animal in each period, where total faeces and urine excretions were collected for seven days. Faeces were collected manually by floor scraping immediately after voiding and weighed each 24 hours. A 200 g sample was then taken and dried at 60° C in a convectional oven overnight to determine dry matter (DM) content and daily dry faecal output. The dried samples for each 7-day collection period were pooled, ground through a 1 mm sieve and stored for later chemical analysis.

Daily urine output was collected into nitrogen free sulphuric acid via a 5 cm diameter hole located at the center of the floor beneath the animal. Daily urine output for each animal was determined and a sample was kept in the refrigerator (4° C). The seven days urine samples were pooled and a sub-sample taken and stored frozen (-20° C) for later energy and nitrogen analysis.

Chemical Analysis

Gross energy (GE) of the diet, faecal and urine (freeze dried) samples was determined via adiabatic bomb calorimetry (PARR model 1241), and nitrogen by macro-Kjeldhal procedure. Proximate analysis of the feed and faecal samples were carried out using A.O.A.C. (1965) procedure.

Metabolisable Energy Intake

Digestible energy (DE) intake for each animal in each period was calculated by multiplying the measured average daily feed intake for the period, gross energy (GE) content and the energy digestibility of the feed. ME intake (MEI) was calculated as DE intake minus urine energy (UE), multiplied by 0.93 to correct for energy due to methane loss (ARC, 1980). No corrections for differences in level of intake were applied.

Maintenance Requirements and Energetic Efficiencies

Maintenance requirements for individual animals were determined for weight equilibrium (Em_{WT}) using quadratic regression of average daily gain (ADG) and MEI (equation 2a) (Sainz et al., 1990). Maintenance requirements for energy equilibrium (Em_{RE}), retained energy in the whole body (RE_{total}), in fat (RE_{fat}) and in protein (RE_{prot}) for individual animals were related to MEI by the equation 2b.

$$ADG = a + bMEI + cMEI^2 \text{ ....(2a).}$$

$$RE = a + bMEI + cMEI^2 \text{ ....(2b).}$$

Equations 2a and 2b were solved for Em_{WT} and Em_{RE} from the roots of the respective equations, viz.

$$Em = (-b + (b^2 - 4ac)^{0.5})/2c \text{ ....(3).}$$

Efficiencies for energy utilization for maintenance for total RE (km_{total}) and that in fat (km_{fat}) and protein (km_{prot}) were estimated as:

$$km = 2c\ (E_m\text{-FHP}) + b \text{ ....(4).}$$

where (E_m-FHP) is the mid-point between E_m and fasting heat production (FHP). The latter was estimated as the Y axis intercept of equation 2b.

The efficiencies of gain of total (k_{total}) energy gain and that in fat (k_{fat}) and protein (k_{prot}) were estimated as the instantaneous slope of the corresponding forms of equation 2b at $1.5E_m$ as suggested by Sainz et al (1990) and calculated as;

$$k = 2c\ (1.5E_m) + b \text{ ....(5).}$$

Due to the curvilinear relationship between gain and intake, there is a level of intake at which gain is maximal. When a quadratic equation is used to define the curve, the maximum (RE_{max}) can be calculated by solving the following equation:

$$RE_{max} = a - b^2/4c \text{ ....(6).}$$

Statistical Analysis

Two cattle and four buffaloes were removed from the experiment at various stages. To salvage the data collected from these six animals before their removal from the experiment, initial overall equations for 2a and 2b were established for the two species using all the data collected from each species. Missing ADG and RE values for the above two cattle and four buffaloes were predicted using the initial overall equations established for the respective species. Similarly, outliers of the RE values measured directly from the experimental animals were examined for reliability and, although no cause of error was identified, these were replaced by best estimates before being used in the regression analysis. A total of 56 missing and outlier values were replaced out of the 499 values used in the regression analysis.

Nutrient digestibilities, body compositions data were statistically analysed for treatment, period, species as were the interactive effects, using the General Linear Model Procedure of the Statistical Analysis Systems (1982). E_m, k_m, k and MAX values were compared for species effects using similar statistical procedure.

RESULTS

Nutrient Digestibilities

DM and GE digestibilities for buffalo were higher ($P<0.05$) than for cattle while that for ether extract was lower (Table II.2). Digestibilities for crude protein (CP) and neutral detergent fibre (NDF) were not significantly different between the animal species. The only significant interactive effect was treatment x species for NDF where NDF digestibility decreased as intake increased for cattle but not for the buffalo. The nutrient digestibility values (except for ether extract) obtained in the study were similar to those reported by Miyashige et al (1987). The lower ether extract digestibility obtained by those workers could be due to the higher ether extract contents (about double) in the feed they used.

Body Compositions

Mean body compositions of the animals predicted using TOH at each period during the experiment are presented in Table II.3. Except for the initial measurement, the mean fat contents of cattle were higher (P<0.01) than those for buffalo. Furthermore while the fat contents for cattle increased gradually from 5.5% initially to 9.2% (P<0.01) at the end of the 40 weeks feeding trial, the fat contents for buffalo remained virtually constant, with an initial value of 5.1% and a final value of 6.1%. Except for the initial value, these differences were not significant. The average fat content obtained from physical dissection at the end of the experiment was 9.6% and 5.9% for cattle (n=8) and buffalo (n=7), respectively. These values were consistent with fat values estimated at the end of period 4 by the TOH procedure, where the fat content of cattle was higher (p<0.05) than cattle (Table II.3). These values were not statistically compared with those estimated by the TOH at end of period 4 because they were not equivalent. The fat contents recorded by physical dissection were carcass plus visceral fats that could be physically separated out, while those by TOH procedure were of total body fat. Protein contents of both species remained constant at about 16.6% of BW (Table II.3).

The statistical analysis indicated significant differences in species, feeding level and species x feeding level interaction for TBF gain but only a feeding level effect for TBP gain (Table II.4). The interactive effect of species x feeding level for TBF gain was because TBF gain increased from M to ad libitum feeding for cattle, but the increase was only from M to 1.8M for buffalo followed by a slight decrease from 1.8M to *ad libitum* feeding level. TBF gains for the three treatment levels above maintenance were higher ($P<0.01$) for cattle than for buffaloes. There were no species differences for TBP gains at all feeding levels (Table II.4).

TBF gain for M was lower ($P<0.01$) than the other three treatments for cattle, and no significant differences were detected among the latter three treatments. For buffalo, the TBF value for M was lower ($P<0.01$) than for 1.8M and *ad libitum* feeding, and no significant differences were detected among 1.4M, 1.8M and *ad libitum* feeding. Similar trends were shown for TBP gains for the two species (Table II.4).

Maintenance Requirements and Energetic Efficiencies

Table II.5 contains the mean regression coefficients for prediction of ADG, RE_{total}, RE_{fat} and RE_{prot} from MEI. Em_{WT} and Em_{RE} for cattle (338 and 335 kJ $kg^{-0.75}$ BW per day, respectively) were about 10% higher ($p<0.05$) than those for buffalo (306 and 313 kJ $kg^{-0.75}$ BW per day, respectively) (Table II.6). Maintenance requirements for fat and protein equilibria were not significantly different between species, although both values for cattle were higher than buffalo. There were no significant differences within species in E_m among ADG, RE_{total}, RE_{fat} and RE_{prot} with overall average of 334 and 310 kJ $kg^{-0.75}$ BW per day, respectively for cattle and buffalo (Table II.6).

The mean k_m value for RE_{total} for cattle (0.64) were higher ($p<0.05$) than that for buffalo (0.48), because of the higher ($p<0.01$) k_m for RE_{fat} for cattle (0.45) as compared to that for buffalo (0.22). Efficiency (k) for RE_{total} for cattle (0.30) was higher ($p<0.05$) than that for buffalo (0.25). Similarly k for RE_{fat} for cattle (0.18) was higher ($p<0.01$) than that for buffalo (0.12). MAX_{total} and MAX_{fat} for cattle (130 and 83 kJ $kg^{-0.75}$ BW, respectively) were higher ($p<0.05$) than those for buffalo (108 and 70 kJ $kg^{-0.75}$ BW, respectively). E_m, k_m, k and MAX for RE_{prot} were not significantly different between the two species (Table II.6 and Figure I.1).

DISCUSSION

Of the 32 animals, 16 animals of each species, used in the experiment, two cattle and four buffaloes were removed at different times during the course of the experiment and all removed animals subsequently died. The actual cause was not confirmed. Liver flukes were found in two of the removed buffaloes. Another possible problem was copper toxicity. Further investigations are currently being undertaken on the possibility of copper toxicity. Palm kernel cake contains 20 to 55 ppm of copper (Jalaludin et al., 1991), which causes copper toxicity symptoms and death in sheep (Hair et al., 1992). No such adverse effects have been reported for cattle or buffalo fed on palm kernel cake. Palm kernel cake was selected as the experimental diet for the present study because of its wide commercial use as the sole dietary ingredient in cattle feedlots in Malaysia.

Body Compositions

While the equations of Little and McLean (1981) for prediction of body compositions from TOH space have not been validated for cattle and buffalo under the present conditions, the carcass dissection data obtained at the end of period 4 were consistent with the TOH based estimates (Table II.3 and Table II.4). These results confirm that the TOH dilution procedure was sensitive enough to detect relative small differences in body water and thus fat content.

The body composition data presented in Table II.3 were means of values at the start and end of each period for both species without taking into account for effects of feeding levels or the order in which feeding treatments were applied. Therefore, the values in Table II.3 only served to indicate the overall changes of the body composition for the two species over times. The higher TBF gains (Table II.4) for cattle than for buffalo at treatment levels above maintenance (1.4M to *ad libitum* feeding) were consistent with the general observation that buffalo deposit fat less efficiently which resulted in more protein in body weight gain than in cattle.

Maintenance Requirements

The 10% higher Em_{WT} and Em_{RE} for cattle than buffalo indicate clear species differences in nutritional efficiency. Similarly, there are physiological (Jainudeen, 1985) and behavioural (Liang et al., 1987) differences between cattle and water buffalo. Fasting heat production (FHP), estimated as the intercept of RE vs. MEI, was also lower for buffalo than that for cattle (179 vs. 302 kJ ME $kg^{-0.75}$ BW). FHP of the present Malaysian KK cattle was 5% lower than the mean value of 319 kJ ME $kg^{-0.75}$ BW for European cattle (ARC, 1980).

Estimated maintenance energy requirements for weight equilibrium (Em_{W-T}) and energy equilibrium (Em_{RE}) for the Malaysian cattle (338 and 335 kJ ME $kg^{-0.75}$ BW, respectively) were also lower than values reported for European cattle. Most published data including ARC (1980) were based on experiments carried out in temperate countries, therefore, differences between the results of the present study and those reported elsewhere may have been due to breed and environmental differences. Solis et al. (1988) reported that maintenance requirements of dry non-pregnant cows of various breed types (*Bos indicus, Bos taurus* and their crosses) varied between 372 to 515 kJ ME $kg^{-0.75}$ BW based on weight equilibrium and between 344 to 587 kJ ME $kg^{-0.75}$ BW based on energy equilibrium. These authors reported that maintenance requirement for beef (Angus and Brahman) types (averaged 391 kJ ME $kg^{-0.75}$ BW) was significantly lower than that for dairy (Holstein and Jersey) types (averaged 536 kJ ME $kg^{-0.75}$ BW), suggesting that maintenance requirements differed as much as 40% among cattle breeds. Frisch and Vercoe (1977) reported that metabolic rates of Bos indicus cattle were lower than Bos taurus cattle. The Malaysia KK cattle are *Bos indicus*, and thus the results of the present study are consistent with literature.

The estimated maintenance energy requirements obtained in the present study were lower than the 425 kJ ME $kg^{-0.75}$ BW and 422 kJ ME $kg^{-0.75}$ BW, respectively for the KK cattle and buffalo reported earlier by Liang et al. (1991) and Liang et al. (1989). The experimental diet in the earlier two experiments consisted of 70% concentrates (Maize, soymeal and tapioca chip in equal proportions) and 30% cut grass, whereas for the present experiment was palm kernel cake. However, the ME concentrations of the two diets were similar at about 9.8 MJ kg^{-1} DM. It is believe that the maintenance requirement values were not affected by diet differences but due to the different procedures by which the data were analysed. In the earlier studies, MEI were used as the dependent variables in a rectilinear model while for the present study, MEI were used as the independent variables in a curvilinear models (see equations 2a and 2b).

Curvilinear equation forms were used in the present study because the relationship between energy retention and intake is curvilinear, due to changes with level of feeding in the proportions of absorbed nutrients, differences in biochemical transactions above and below maintenance, changes in metabolic rate, or in actual efficiency of fat and protein synthesis (ARC, 1980).

Energetic Efficiencies

The estimated k_m values for RE_{total} obtained for the KK cattle (0.64) and for buffalo (0.48) were lower than ARC (1980) preferred value of 0.70 (based on a qm of 0.55 as in the present study). The differences could be due to genetic differences as discussed earlier. The 25% higher k_m for RE_{total} ($p<0.05$) for cattle than for buffalo indicating that cattle utilised ME below maintenance more efficiently than do buffalo.

As suggested by Sainz et al. (1990), the slope of the curvilinear equation of RE on MEI at $1.5E_m$ (k) was desirable for comparison with the k_f values reported by ARC (1980). They further pointed out that while k_{total} is equivalent to ARC's estimates of k_f, k_{fat} and k_{prot} measured in their study and, in the present study as well, do not correspond to commonly accepted partial efficiencies of fat and protein gain. But rather, they are indices of the partition of available ME into body fat and protein respectively. The preferred k_f (0.44) from ARC (1980) over-predicted the k for RE_{total} obtained for cattle (0.30) and for buffaloes (0.25) in the present study by 13% and 43%, respectively. Hogan and Liang (1991) cited literature reported that under non-stressful conditions, tropical *Bos indicus* cattle grew only about 0.8 the rate of temperate *Bos taurus* cattle, and the reduced productivity was suggested to be "the price paid" by the tropical cattle to adapt to the tropical environment. The lower energetic efficiencies of the KK cattle and buffalo as compared to that suggested by ARC (1980), which mainly based on data derived from temperate countries is thus consistent. The low efficiencies of gain recorded here are reflected in the slow growth rates generally observed for KK cattle and buffalo. The best values reported for growth rates of KK cattle and buffalo under excellent intensive feeding conditions were about 0.6 kg d^{-1} (Shamsudin, et al., 1987; Mohd. Shukri et al., 1987).

Table II.1 Chemical composition and gross energy of palm kernel cake (n=4)

Dry matter (g kg^{-1} DM)	881
Crude protein (g kg^{-1} DM)	168
Neutral detergent fibre (g kg^{-1} DM)	757
Acid detergent fibre (g kg^{-1} DM)	614
Ether extract (g kg^{-1} DM)	25
Ash (g kg^{-1} DM)	45
Gross energy (MJ kg^{-1} DM)	17.9

Table II.2 Least square means of nutrient digestibility coefficients of palm kernel cake

Nutrients	Cattle (n=62)	Buffalo (n=54)	(s.e.)
Dry matter	0.719[a]	0.737[b]	(0.005)
Gross energy	0.700[a]	0.718[b]	(0.006)
crude protein	0.724	0.738	(0.007)
Ether extract	0.887[a]	0.809[b]	(0.010)
Neutral detergent fibre	0.796	0.789	(0.006)

a b: means with different superscripts in the same row are significantly different ($P<0.05$)

Table II.3 Least square means of water, fat and protein contents (% of BW) of the animals estimated by TOH dilution procedure at different periods (P) together with fat contents by direct carcass dissection at the end of experiment

Parameters	Water		fat		protein	
	cattle	buffalo	cattle	buffalo	cattle	buffalo
Initial*	71.15	72.64	5.48	5.05	16.35	16.48
(s.e.)	(0.36)	(0.39)	(0.35)	(0.38)	(0.02)	(0.02)
End of P1*	70.59[a]	72.10[b]	6.97[b]	5.48[a]	16.60	16.56
(s.e.)	(0.38)	(0.40)	(0.37)	(0.39)	(0.01)	(0.02)
End of P2*	69.56[a]	71.53[b]	7.78[b]	5.99[a]	16.65	16.62
(s.e.)	(0.37)	(0.41)	(0.36)	(0.39)	(0.01)	(0.01)
End of P3*	68.94[a]	71.71[b]	8.44[b]	5.74[a]	16.70	16.66
(s.e.)	(0.37)	(0.37)	(0.36)	(0.36)	(0.01)	(0.01)
End of P4*	68.17[a]	71.30[b]	9.18[b]	6.09[a]	16.73	16.70
(s.e.)	(0.37)	(0.41)	(0.36)	(0.39)	(0.01)	(0.02)
By Dissection*			9.62[b]	5.92[a]		
(s.e.)			(0.63)	(0.67)		

[a], [b]: means with different superscripts in the same row for each parameter are significantly different (P<0.01)

* n Initial to P3 = 16 cattle and 16 buffaloes,
n P3 to P4 = 15 cattle and 12 buffaloes,
n by dissection = 8 cattle and 7 buffalo.

Table II.4 Least square means of total body fat (TBF) and total body protein (TBP) gains at each feeding levels for cattle and buffalo

	Treatment	Cattle	(n)	Buffalo	(n)
TBF (g day^{-1})	1.0M	10.43 ± 5.59	(15)	$11.51^{x} \pm 5.80$	(13)
	1.4M	$61.89^{ay} \pm 5.40$	(16)	$25.77^{bxy} \pm 5.85$	(13)
	1.8M	$71.77^{ay} \pm 5.59$	(16)	$44.94^{by} \pm 5.59$	(15)
	ad lib	$76.94^{ay} \pm 5.59$	(15)	$41.88^{by} \pm 5.59$	(15)
TBP (g day^{-1})	1.0M	$13.73^{x} \pm 5.65$	(15)	$10.60^{x} \pm 5.87$	(13)
	1.4M	$69.32^{y} \pm 5.47$	(16)	$60.42^{y} \pm 5.92$	(13)
	1.8M	$80.96^{yz} \pm 5.65$	(16)	$81.95^{z} \pm 5.65$	(15)
	ad lib	$92.67^{z} \pm 5.65$	(15)	$78.13^{z} \pm 5.65$	(15)

^{a}, ^{b}: means with different superscripts in the same row are significantly different (P<0.01)

^{x}, ^{y}, ^{z}: means with different superscripts in the same column are significantly different (P<0.01)

Table II.5 Regression coefficients and their standard errors for prediction of ADG and energy retained (RE) in fat, protein and total from ME intake (MEI) for KK cattle and buffalo. All units in kJ $kg^{-0.75}$ per day

	a		b		c	
	KK	Buffalo (s.e)	KK	Buffalo (s.e.)	KK	Buffalo (s.e.)
ADG	-.036	-.025 (.005)	.00016	.00011 (.0000)	-.00000	-.00000 (.00000)
Fat	-185.8^{a}	-77.0^{b} (18.9)	$.7175^{a}$	$.2976^{b}$ (.0761)	$-.00053^{a}$	$-.00018^{b}$ (.00007)
Protein	-116.4	-103.4 (15.9)	.4622	.4249 (.0663)	-.00033	-.00030 (.00006)
Total	-302.2	-178.7 (30.6)	1.1797	.7162 (.1266)	-.00085	-.00048 (.00012)

^{a,b}: means with different supedrscripts in the same row were significantly different ($p<0.05$).
Model fitted was: $RE = a + bMEI + cMEI^2$

Table II.6 Least square means and standard errors of maintenance energy requirement (E_m), efficiency for maintenance (k_m), for gain (k) and maximal gain (MAX) for KK cattle and buffalo. All values are kJ $kg^{-0.75}$ per day

	E_m		k_m		k		MAX	
	KK	Buffalo (s.e.)	KK	Buffalo (s.e.)	KK	Buffalo (s.e.)	KK	Buffalo (s.e.)
ADG	337	306 (9)	-	-	-	-	-	-
Fat	338	321 (7)	$.45^a$	$.22^b$ (.04)	$.18^a$	$.12^b$ (.01)	83^a	70^b (11)
Protein	328	301 (10)	.31	.30 (.04)	.12	.13 (.01)	77	72 (16)
Total	335^a	313^b (7)	$.64^a$	$.48^b$ (.05)	$.30^a$	$.25^b$ (.01)	130^a	108^b (12)

[a,b]: means with different superscripts in the same row significantly different ($p<0.05$)

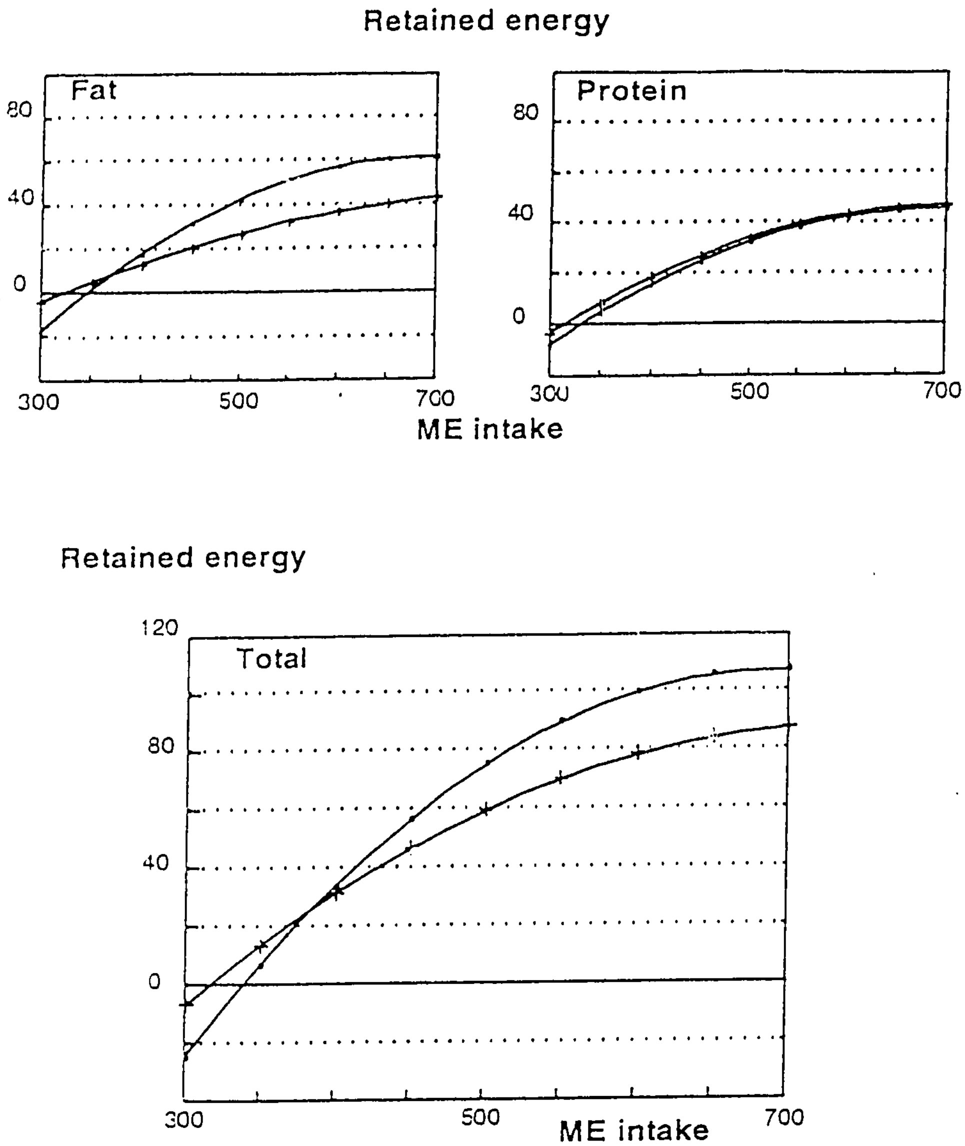

Figure II.1 Energy retained as fat, protein and total as a function of ME intake fitted using derived equations for KK cattle (•) and swamp buffalo (+). All values aare in kJ $kg^{-0.75}$ BW per day.

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III. PURINE DERIVATIVE EXCRETION AND RUMINAL MICROBIAL YIELD IN MALAYSIAN CATTLE AND SWAMP BUFFALO

INTRODUCTION

In ruminants, allantoin is the main product of purine catabolism, and the principal purine derivative in urine. Studies by Topps and Elliott (1965) and Smith and McAllan (1970) have shown that urinary allantoin is derived predominantly from microbial nucleic acids and, therefore, could serve as an indicator of microbial breakdown. Rys et al. (1975) cited literature showing that 0.18 of the microbial N leaving the rumen was as nucleic acids, and that 0.25 of the N in these nucleic acids appeared in urine as allantoin. From this, they suggested that microbial nitrogen (N) outflow rate from the rumen could be estimated from urinary allantoin N excretion rate divided by 0.045. The catabolic pathways for conversion of purine bases of microbial nucleic acid reduction to urinary allantoin involve hypoxanthine, xanthine, uric acid and allantoin (Oser, 1965). Chen et al. (1990a) demonstrated a linear response in urinary excretion of allantoin with intra-duodenal infusion of exogenous nucleic acids. However, the recovery of purine derivatives in urine in response to these infusions was not quantitative. These workers showed that 0.16 of the plasma purine derivatives were lost through channels other than renal excretion, presumably through losses via saliva and direct secretion of

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purine derivatives into the gut. Furthermore, species (Vercoe, 1976; Chen et al., 1990b; Fujihara et al., 1991), diet and feed additives (Dewhurst and Webster, 1992) affect the excretion of the urinary purine derivatives presumably through modification of gut microbial activity, and thus alteration of cell nucleic acid content or flow of microbial cells from the rumen.

Dry-matter (DM) and gross energy digestibilities of palm kernel cake were found to be higher for buffalo than for cattle (Chapter II). These results confirmed earlier experiments which detected differences in rates of digestion by the two species (Liang and Samiyah, 1988; Abdullah et al., 1990). Information on the microbial population of these cattle and buffalo would be useful to explain the species differences in digestion rates.

In the first of two experiments, urinary allantoin excretions of the experimental animals in Chapter II were measured and used to predict ruminal microbial yields. The second experiment investigated possible species differences in the form of purine excretion from animals in fed and fasted states, and to estimate minimal endogenous excretion of purine derivatives.

MATERIALS AND METHODS

Experiment 1

Animals and treatments: Entire male Kedah-Kelantan (KK) cattle (*Bos indicus*) with an initial body weight of 149.2 ± 16.9 kg and male swamp buffalo (*Bubalus bubalis*) of an initial weight of 137.3 kg ± 21.5 kg were used in a double 4x4 latin square experiment, replicated four times for each species, i.e., 16 animals per species. The animals were fed in individual stalls at four feeding levels; at maintenance (assumed to be 425 kJ ME $kg^{-0.75}$ BW), 1.4M, 1.8M and *ad libitum* intakes in four 10-week periods. Palm kernel cake pellet was the sole diet (9.8 MJ ME kg^{-1} DM, and crude protein of 16.8%).

Urine collection and analysis for allantoin: During seven days digestibility measurements during the 5th week of each 10 week period, daily urine voided by each animal was collected into N free sulphuric acid via a 5 cm diameter hole located at the center of the shaped concrete floor beneath each animal. After weighing, a proportion of the urine was sampled and stored in a refrigerator at 4°C. At the end of the seven day collection period, urine samples were pooled within animal and sub-samples were taken and stored frozen at -20°C until analysis for allantoin 2 to 4 weeks later. A total of 59 and 56 urine samples, respectively, for cattle and buffalo were analysed. Allantoin contents were determined by the Rimini-Schryver reaction using a modification reported by Young and Conway (1942), and converted to N equivalent.

Data Analysis: Using least square procedure, the allantoin excretions were regressed against digestible DM intakes (DDMI) using rectilinear and curvilinear models where (Y = urinary allantoin excretion, g N day^{-1}; X = DDMI kg day^{-1}). During the 40 weeks testing period, the body weight (BW) of the animals varied widely, between 116 kg to 269 kg for cattle and 117 kg to 260 kg for buffalo. The regression analysis were therefore repeated after adjusting for allantoin excretion and food intake per $kg^{-0.75}$ BW and also for DDMI:BW ratio.

The values not adjusted for BW gave the highest coefficients of determination ($R^2 = 0.76$ and 0.65, respectively for cattle and buffalo), and curvilinear models did not improve the relationships. The rectilinear intercepts were considered to represent the minimal endogenous allantoin excretion, and the slope the rate of increase in allantoin excretion per unit DDMI. These were statistically compared for species differences using t-tests.

Experiment 2

Animals and treatments: Four cattle (251.5 ± 3.4 kg) and four buffaloes (235.3 ± 6.3 kg) were selected from Experiment 1 for the second study. Immediately after Experiment 1, the animals continued to be fed on palm kernel cake pellet at a DM level of 1% of their body weight for the three days prior to commencement of Experiment 2. The 14 days test period of this experiment consisted of two days of feeding at 1% of body weight, six days of fasting (drinking water was provided), followed by six days of refeeding. The refeeding schedule consisted of two days each at DM intake levels of 0.5%, 1% and 1.5% of their respective body weight. Daily urine samples were collected and stored at 4°C in similar manner as in Experiment 1.

Purine derivatives analysis: Allantoin contents of the urine samples were analysed as in Experiment 1. Uric acid and the combined concentrations of hypoxanthine and xanthine (determined after conversion to uric acid by xanthine oxidase) were estimated using spectrophotometer in optical density at 293 nm as described by Fujihara et al., (1987).

Data analysis: Values were combined over two consecutive days within animal. Allantoin, uric acid and the combined hypoxanthine and xanthine contents were converted to N equivalents using the N contents values of allantoin = 53.4%, uric acid = 33.3%, hypoxanthine and xanthine = 36.8%. The different measured parameters were compared for species and feeding treatments using General Linear Models Procedures of SAS (1982).

RESULTS

Experiment 1

Allantoin excretion: The rectilinear relationships between allantoin excretion (Y; g N day^{-1}) and DDMI (X; kg day^{-1}) were:

$$Y_{cattle} = 0.238(\pm 0.120) + 0.836(\pm 0.062)\ X1\ (R^2 = 0.76,\ p<0.01)\ ...\ \text{(Equation i)},$$

$$Y_{Buffalo} = 0.181(\pm 0.088) + 0.466(\pm 0.047)\ X2\ (R^2 = 0.65,\ p<0.01)\ ...\ \text{(Equation ii)}.$$

There were no significant differences between the two intercepts, but the slope for cattle was greater ($P<0.01$) than that for buffalo (Figure III.1). The relationships between allantoin and DDMI adjusted for BW and DDMI:BW ratio had R^2 values of 0.74 and 0.54 for cattle and buffalo, respectively, while for DDMI:BW, the respective values were 0.40 and 0.34.

Experiment 2

Purine derivative excretions: Allantoin, the principal urinary purine excreted, ranged between 74% to 86% for cattle and 60% to 75% for buffalo (Table

III.1). The combined hypoxanthine-xanthine excretions were minor for both species, ranging from 1 to 3% of the total purine N excretions. Therefore, the hypoxanthine and xanthine contents were added to the uric acid content of the respective animals and, hereafter, referred to as simply uric acid. The adjusted uric acid contributed between 14% to 26% of the total purine for cattle and 25% to 40% for buffalo.

Cattle excreted three times as much allantoin (Table III.1) as buffalo ($p<0.01$) at the beginning of the experiment (PF), when the animals were fed DM at 1% of body weight. Although the differences between species decreased, the values for cattle remained significantly higher except during the last two days of fasting (F3) and the first two days of refeeding (RF1). Feeding regimes affected allantoin excretions of cattle but not buffalo. In cattle, allantoin excretions decreased from the beginning of the experiment (PF) (1.738 g N day^{-1}) to the end of the fasting (F3) (0.742 g N day^{-1}) and, thereafter increased with refeeding until the end of the experiment (RF3) (1.214 g N day^{-1}). Although buffalo followed a similar pattern, the changes were less pronounced and not significantly different (Table III.1).

Uric acid excretion of cattle declined gradually from the beginning of the trial (PF) (0.415 g N day^{-1}) to the end of the trial (RF3) (0.206 g N day^{-1}), while those of buffalo tended to remained almost constant up to end of fasting (F3) before declining during refeeding (Table III.1). The values for buffalo were higher than those of cattle especially towards the end of fasting (F2 to F3, $p<0.05$), but not significantly different when the animals were fed (PF, RF1 to RF3) and during early fasting (F1).

The higher uric acid excretions of buffalo towards the end of fasting (F2 and F3) compensated quantitatively for their lower allantoin excretions at those periods. This resulted in a narrower difference in total purine N excretion between cattle and buffalo at the end of fasting. However, these values remained non- significant between cattle and buffalo (Table III.1). The total purine excretions for cattle remained higher than those for buffalo for the rest of the measurements, when the animals were fed (PF), refed (RF2 and RF3) and at the initial fasting (F1).

Endogenous excretion: The excretions measured for the various derivatives at the end of fasting (F3) were taken as endogenous excretions rates for comparative purpose. Endogenous allantoin excretion of cattle and buffalo was not statistically different, averaged 0.628 g N day^{-1}. Endogenous uric acid excretion was higher ($p<0.05$) for buffalo (0.343 g N day^{-1}) than cattle (0.257 g N day^{-1}), however, the total endogenous purine for the two species was not significantly different, averaged 0.927 g N day^{-1} (Table III.1).

DISCUSSION

Allantoin Excretion

The rates of allantoin excretions obtained in Experiment 1 of the present study were close to Vercoe's (1976) values of 0.86 g N kg^{-1} DDMI and 0.37 g N kg^{-1} DDMI for cattle and buffalo, respectively. The rate of increase in allantoin excretion for sheep ranged between 0.64 to 1.70 mg N g^{-1} DDMI (Dewhurst and Webster, 1992), and at a high value of 2.46 mg N g^{-1} DDMI has been reported for lesser mouse-deer (*Tragulus javanicus*) fed on Lundai (*Sapium baccatum*) by Nolan et al. (1993). These values further indicating species differences in urinary allantoin excretions and apparent rumen microbial protein outflow per DDMI.

Chen at al. (1992) detected a positive relationship between purine excretion and DMI:BW ratio on sheep ($R^2 = 0.50$), and suggested that purine excretions were related to ruminal kinetics. Their arguments were based on the assumption that BW is indicative of ruminal volume, and the DMI:BW ratio is an indicator of the rate of turnover (dilution rate) of the rumen biomass. The positive relationship between purine excretion and DMI:BW ratio was presumed to indicate that passage rate of smaller animals (higher DMI:BW ratio) was greater than that of larger animals given the same relative amount of food. Positive relationships were obtained for allantoin and DDMI:BW for cattle ($R^2 = 0.40$) and buffaloes ($R^2 = 0.34$) in Experiment 1, but these regressions were more variable than the values that were not body weight adjusted.

Purine Derivatives Excretion Patterns

The minor amount of hypoxanthine and xanthine of cattle and buffalo measured in the present experiment (Table III.1) were consistent with the results of Chen et al. (1990b). These workers reported that hypoxanthine and xanthine were not detectable in urine of cattle, but were present in substantial amounts in sheep and pig because of the absence of xanthine oxidase in the plasma of sheep and pig.

The rates of decline in allantoin excretion in fasting animals in the present experiment were slow compared to those recorded by Fujihara et al. (1991) for sheep and goat fed on timothy hay, where base line measurements were obtained within a day or two after the start of fasting. Although rumen turnover rates of cattle and buffalo are generally slower than the smaller species, the rates of passage of cattle and buffalo in the present study were expected to be fairly rapid because of the ground and pelleted diet. The present data indicates that the allantoin excretion was still falling after six days fasting (F3). The minimal value (Figure III.2 and Table III.1) may not have been reached and, therefore, the F3 values in the present experiment may be an overestimation of the minimal endogenous excretion rate of cattle and buffalo. Chen et al (1990a) hypothesized that endogenous contribution decreased as the supply of exogenous purines increased, with an associated progressive replacement of *de novo* synthesis from exogenous sources. These workers argued that endogenous contributions in normally fed sheep nourished above 0.8 times their maintenance energy requirement decreased to zero.

Knowing that allantoin excretions in fed cattle were higher than buffalo (Experiment 1 and Vercoe, 1976), we sought in Experiment 2 to determine whether other derivatives excretions (hypoxanthine, xanthine and uric acids) of buffalo were higher than those of cattle to account for their lower allantoin excretions. The results indicated that the total purine derivative excretions for cattle were higher irrespective of form than those of buffalo under feeding condition (Table III.1). Since urinary allantoin excretion and DDMI was highly correlated (see Equation i), we suggest that urinary allantoin excretion serves as a useful index for ruminal microbial outflow in cattle and buffalo. The use of total purine excretion rather than allantoin was not considered necessary because it requires extra laboratory analysis and did not provide any predictive advantage.

Estimation of Microbial Yield

Rumen microbial production depends on availability of free energy in the rumen and can be predicted from metabolisable energy (ME) intake (ARC, 1984). When calculating microbial N (MN) by dividing excretion of allantoin N (coefficient b of Equation i) by 0.045 per Rys et al. (1975) gave a value of 18.4 g MN per DDMI for KK cattle. This value when converted to per MJ ME intake (ME of palm kernel cake = 9.8 MJ kg^{-1} DM or 12.6 MJ kg^{-1} DDMI, Chapter II) gave a value of 1.4 g MN per MJ ME intake for KK cattle, which is similar to that suggested by ARC (1984). However, similar calculation gave a value of 0.8 g MN per MJ ME intake for buffalo, about 60% of the value for cattle.

Microbial N (MN) yields were estimated to assess their contributions to net N depositions (ND) of cattle and buffalo of a standardized 200 kg BW when fed palm kernel cake at maintenance (M) and 2M levels (based on maintenance requirements of 335 and 313 kJ $ME^{-0.75}$ per day in Chapter II for KK cattle and swamp buffalo, respectively). The estimated MN for cattle (26 g day^{-1}) fed at M level was 1.6 times higher than buffalo (16 g day^{-1}). The difference increased further to 1.7 times at 2M feeding (47 g day^{-1} vs 27 g day^{-1}).

Metabolisable protein (MP = MCP + DUP) for KK cattle and buffalo at the assumed standardised weight of 200 kg fed at M and 2M feeding levels was estimated using the procedures adopted by the Metabolisable Protein System (Alderman, 1992), where MP is metabolisable protein, MCP is microbial crude protein and DUP is digested undegradable protein. Since DUP were not measured in the present study, DUP preferred values by the Metabolisable Protein System for the respective intake levels were used for the calculations. At M intake, the estimated MP values for KK cattle (146 g day^{-1}) was 95% of the Metabolisable Protein System's values (155 g day^{-1}), however, the estimated MP value for buffalo (106 g day^{-1}) was 32% lower than the predicted value. Similarly, the estimated MP value for KK cattle (363 g day^{-1}) at 2M feeding level was within 10% error range (1.08) of the suggested value (337 g day^{-1}) but that for buffalo (286 g day^{-1}) was 15% lower.

Because of their lower MP (due to lower MCP yield), buffalo showed a higher apparent efficiency for N deposit when given the same type and level of diet. Although factors which affect net ND were not measured in the present study, there is evidence to indicate species differences in rate of passage (Liang and Samiyah, 1988; Kennedy et al., 1992), digestion rate (Abdullah et al., 1990, Fujihara et al., 1991) and microbial types (Imai et al., 1992). Variations in the nucleic acid content because of differences in types of rumen micro-organism or their rate of growth (McAllan, 1982) could result in different allantoin contents detected between cattle and buffalo. Therefore, the use of a common factor (0.045) per Rys et al. (1975) to calculate microbial N from allantoin N for species comparison such as cattle and buffalo needs further investigation.

Chen et al. (1992a) reported 0.16 of the plasma purine derivative were lost through mechanisms other than renal excretion, presumably via saliva into the rumen and direct secretion into the gut in sheep. It is postulated that the lower allantoin content detected in the urine samples of buffalo was, at least partly, due to higher allantoin recycling rate in buffalo than cattle. This assumption ...sed on the fact that transfer of urea to the rumen was found to be higher in buffalo than cattle (Kennedy et al., 1992). The higher N recycling (in the form of urea and perhaps in allantoin), could be an adaptive feature of buffalo by which they can maximise N utilization to their advantage under their normal environment, where poor quality roughage is the main source of food. However, the estimated recycling rate of buffalo must be 40% higher than cattle in order to explain for the present difference in urinary allantoin contents for the two species. This recycling value seems to be very high, but not biologically impossible. Kennedy et al. (1992) reported the transfer of urea to rumen in buffalo was 50% higher than cattle (7.4 g N day^{-1} v. 3.4 g N day^{-1}).

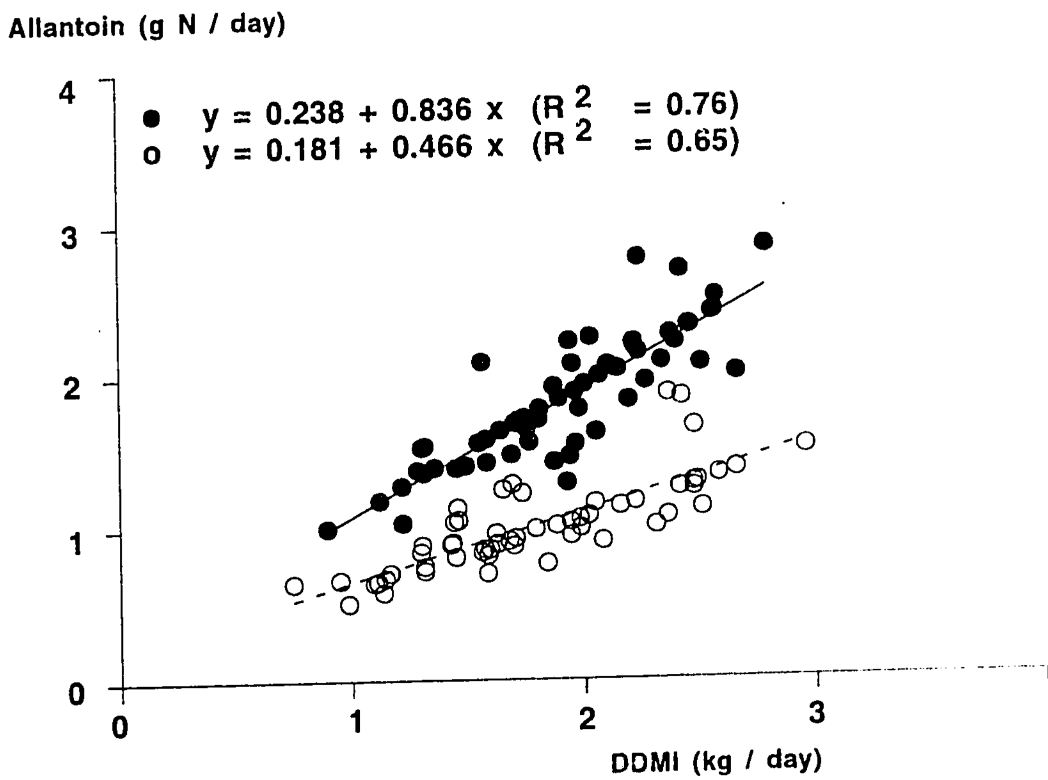

Figure III.1 Urinary allantoin excretion of KK cattle (●), and buffalo (O) as a funtion of digestible dry matter intake (DDMI).

Table III.1. Least square means of purine derivatives excretion (g N/d) of cattle and buffalo prior fasting (PF), early fasting (F1), mid fasting (F2), end of fasting (F3), early refeeding (RF1), mid refeeding (RF2) and end of refeeding (RF3).

		Cattle (n=8)	Buffalo (n=8)	s.e.	Species diff.
Allantoin					
PF	(1.0%)	1.738^{a}	0.594	1.19	0.01
F1	(0.0%)	1.350^{b}	0.668	1.19	0.01
F2	(0.0%)	1.030^{bc}	0.618	1.19	0.01
F3	(0.0%)	0.742^{c}	0.513	1.19	n.s.
RF1	(0.5%)	0.868^{bc}	0.637	1.19	n.s.
RF2	(1.0%)	1.128^{b}	0.649	1.19	0.05
RF3	(1.5%)	1.214^{ab}	0.715	1.19	0.05
Uric acid					
PF	(1.0%)*	0.415^{a}	0.391^{a}	0.36	n.s.
F1	(0.0%)	0.323^{ab}	0.282^{b}	0.36	n.s.
F2	(0.0%)	0.275^{b}	0.386^{a}	0.36	0.05
F3	(0.0%)	0.257^{b}	0.343^{a}	0.36	0.05
RF1	(0.5%)	0.235^{bc}	0.265^{b}	0.36	n.s.
RF2	(1.0%)	0.334^{b}	0.219^{b}	0.36	n.s.
RF3	(1.5%)	0.206^{c}	0.244^{b}	0.36	n.s.
Total purine					
PF	(1.0%)	2.153^{a}	0.984	1.45	0.01
F1	(0.0%)	1.673^{b}	0.951	1.45	0.01
F2	(0.0%)	1.305^{bc}	1.008	1.45	n.s.
F3	(0.0%)	0.998^{c}	0.856	1.45	n.s.
RF1	(0.5%)	1.102^{bc}	0.902	1.45	n.s.
RF2	(1.0%)	1.462^{b}	0.867	1.45	0.05
RF3	(1.5%)	1.419^{b}	0.959	1.45	0.05

$^{a, b, c}$: means with different superscripts in the same column are significantly differenc ($p<0.05$)

* Feeding level (DM % body weight).

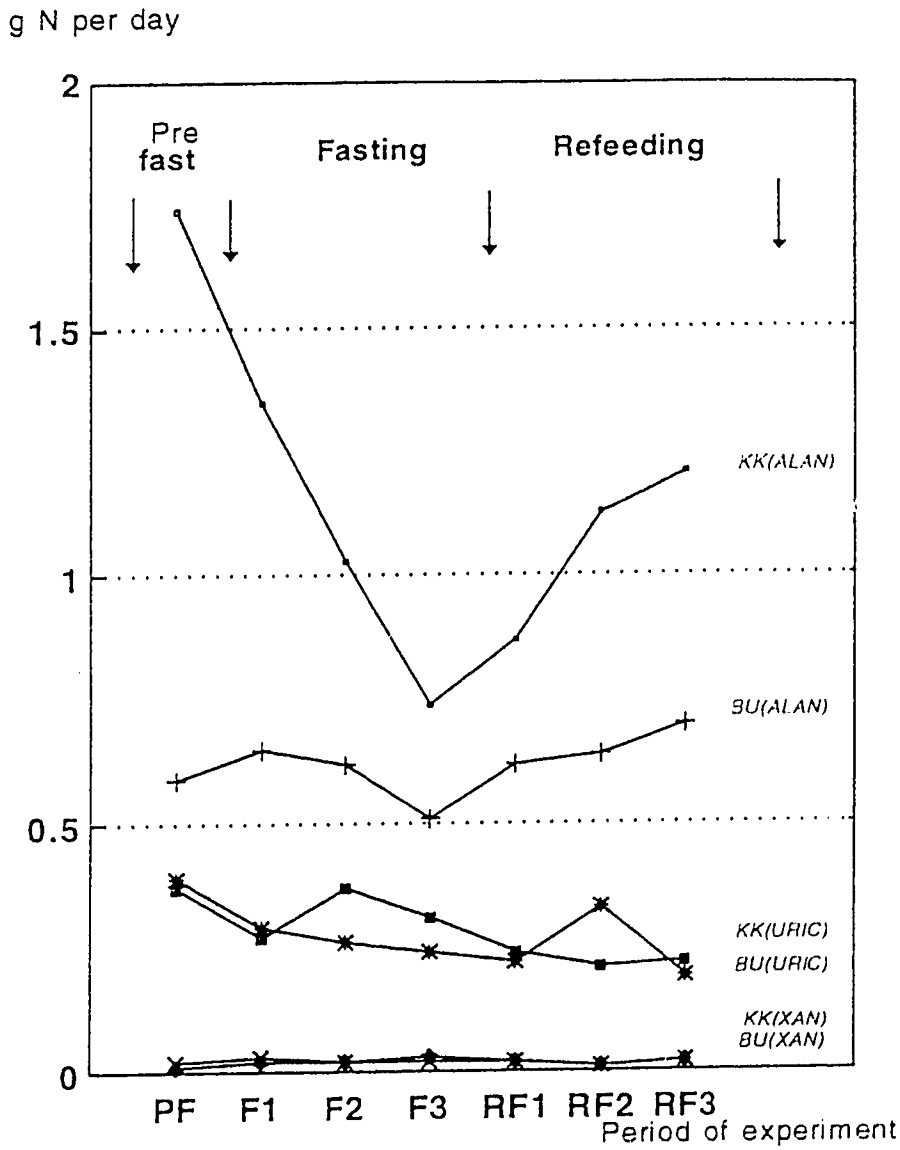

Figure III.2 Urinary allantoin (ALAN), uric acid (URIC) and hypoxanthine + xanthine (XAN) excretions of KK cattle (KK) and swamp buffalo (SB) at pre fast (PF), early fasting (F1), mid fasting (F2), end fasting (F3), early refeeding (RF1), mid refeeding (RF2) and end of refeeding (RF3).

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IV. ENERGETIC EFFICIENCIES OF DIFFERENT BREEDS OF CATTLE AND BUFFALO IN MALAYSIA

INTRODUCTION

Kedah Kelantan (KK) cattle (*Bos indicus*) and swamp buffalo (SB) (*Bubalus bubalis*) are indigenous to Malaysia, providing the bulk of meat (beef) for local consumption. On the other hand, Sahiwal x Friesian (SF) crossbred (*Bos indicus x Bos taurus*), imported from Australia and New Zealand and Murrah buffalo (MB) (*Bubalus bubalis*), brought in by the early immigrants from India are the two main dairy animals used for fresh milk production locally.

In Chapter II energetic efficiencies of KK and SB were compared using a 4x4 latin square trial with four levels of feeding (maintenance to *ad libitum* feeding). The results of that study showed that KK had higher energetic efficient for fat deposition than SB, but no significant difference was detected in efficiency for protein deposition between the two species.

The present study further investigates energetic efficiencies of two breeds of cattle (KK and SF) and two breeds of buffalo (SB and MB) under Malaysian conditions. In addition to examine breeds differences, the present study also sought to investigate differences between sex (male vs female), species (cattle vs. buffalo) and commercial use of animals (beef vs dairy), which are the most common large ruminants in Malaysia.

MATERIALS AND METHODS

Animal and Diet

The experiment was conducted at the Malaysian Agricultural Research and Development Institute Research Station, Serdang from May 1992 to October 1992. Eight yearling animals (4 males and 4 females) of each type (breed) (KK, SF, SB and MB) were tested in two 70-day periods feeding trial. The animals had initial body weight of 102.7 ± 6.9 kg, 131.2 ± 2.3 kg, 128.1 ± 7.7 kg and 150.6 ± 6.9 kg, respectively for KK, SF, SB and MB, were purchased from commercial farms. The experimental diet was palm kernel cake pellet (Table IV.1), same as that used in Chapter II. During a pre-trial period of 1 month, the animals were fed at 650 kJ ME $kg^{-0.75}$ BW per day. Vitamin supplement (containing 800,000 i.u. vitamin A, 400,000 i.u. vitamin D3 and 200 mg vitamin E), were given intra-muscularly to all animal at the beginning of each period.

Experimental Design

The experiment consisted of two 70-day feeding periods. Four animals (2 males and 2 females) per breed were fed each treatment level (700 kJ ME $kg^{-0.75}$ BW or *ad libitum*) during each period. Animals fed *ad libitum* in period 1 were given 700 kJ ME $kg^{-0.75}$ BW feeding in period 2 and vice versa so that each animal underwent the two feeding treatments. Animals fed *ad libitum* intake were offered 10% more than their previous day *ad libitum* intake.

Intake and Body Weight

The animals were housed in individual stalls of 1.2 x 2.5 meter. Fresh feed was weighed daily and offered once a day at 0900 h to each animal after the removal of any feed residual from the previous day. The difference between the amount of feed offered and the residue removed was taken as the amount consumed. Feed spillage and losses was minimal (< 2% of feed offered). Measures of daily feed intake were pooled and averaged over each week. Clean water and mineral blocks (containing on per kg basis, 380 g sodium, 5 g magnesium, 1.5 g of iron, 300 mg each of zinc and copper, 200 mg of manganese, 150 mg of iodine, 50 mg of cobalt and 10 mg of selenium) were available at all times. Body weight (BW) was measured weekly on Tuesday and the new BW of each animal was used as the basis to calculate the daily feed allocation for the following seven days. The weekly BW of each animal for each period were regressed against time using rectilinear regression;

$$BW\ (kg) = a + b\ \text{day} \quad ....(1)$$

The intercept (a) was taken as the adjusted initial BW and the slope (b), the average daily gain (ADG) for each 70 days period. Adjusted final BW for each period was calculate using equation 1 for each individual.

Body Composition and Retained Energy

The initial and final body compositions for each animal for each feeding period were estimated using tritiated water (TOH) dilution technique of Little and McLean (1981). Further details of TOH injection and analysis of tritium concentration in the blood samples are described in Chapter II). Retained energy (RE) of individual animal was determined for each period from the initial and final total body fat and protein, based on the adjusted initial and final BW and assumed calorific value of 39.3 kJ g^{-1} and 23.6 g^{-1} for fat and protein, respectively (Garrett and Hinman, 1969).

Digestibility Trials

Total faeces and urine voided were collected for a seven days as described in Chapter II. Since no significant differences were detected in the apparent digestibilities of nutrients among the four feeding levels in Chapter II using the same diet (palm kernel cake) as in the present experiment, diet digestibility values were determined only in period 1.

Metabolisable Energy Intake

Digestible energy (DE) for each animal in each period was calculate by multiplying the measured average feed intake for the period, gross energy (GE) content and the energy digestibility of the feed. ME intake (MEI) was calculated as DE intake minus urine energy (UE), multiplied by 0.93 (Chapter II).

Energetic Efficiency

Retained energy (RE) in fat (RE_{fat}), in protein (RE_{prot}) and in whole body (RE_{total}) were pooled for breeds and regressed against MEI using rectilinear equation as shown below:

$$RE = a + b\ MEI \ ....(2)$$

The slope (b) was taken as the efficiency (k) of ME used for each unit of RE.

Energy Retention

Maximal RE for fat (MAX_{fat}), protein (MAX_{prot}) and total (MAX_{total}) and RE at a standardised . . e (700 kJ kg$^{-0.75}$ BW) for fat (FAT_{700}), protein ($PROT_{700}$) and Total ($TOTAL_{700}$) for the four breeds were estimated using the respective established equations of (2).

Statistical Analysis

Efficiency (k) values were compared for breed, sex, species (cattle vs buffalo), functional type (meat vs dairy) effects using procedure of comparison of regression lines described by Snedecor and Cochran (1980). Sex, effect was found to be not significant, therefore, data within breed were pooled for sex and reanalysed. Breeds differences were found to be significant for k_{fat}, k_{prot} and k_{total}, therefore, data were not pooled to determine for species and functional type differences. Mean of the two feeding levels were analysed for breeds differences using the General Linear Model Procedure of SAS (1982).

RESULTS

Efficiency

The estimated coefficient efficiencies for the four breeds are shown in

Table IV.2. The k_{fat}, k_{prot} and k_{total} of the four breeds calculated from these coefficiencies are presented in Table IV.3. K_{fat} for SB (0.14) was the highest, followed by those of KK (0.13), SF (0.11) and MB (0.10). k_{fat} of two beef types (SB and KK) was not significantly different, but were higher than the two dairy types (SF and MB). k_{fat} was not significant between the two dairy types. Comparisons of k_{prot} among the four breeds were less consistent than k_{fat} (Table IV.3). K_{prot} of KK, SB and MB differed significantly among breeds with KK (0.10) been the highest, followed by MB (0.08) and SB (0.07). However, although been the lowest among the four breeds tested, k_{prot} of SF (0.06) was not significantly different from the other three breeds. K_{total} of KK, SB and MB were significant different among breeds in the order of KK (0.22), followed by SB (0.20) and MB (0.18). As in the case of k_{prot}, k_{total} of SF was the lowest (0.17), but were not significant from KK and SB.

Intake and Energy Retention

Table IV.4 contained the mean values of the two feeding levels, and the estimated maximal RE (*MAX*) and at a standardised intake level of 700 kJ ME $kg^{-0.75}$ BW of the four breeds. Most animals offered 700 kJ $kg^{-0.75}$ BW feeding level did not finished the feed. The average intake for this treatment level was 622, 715, 563 and 630 kJ $kg^{-0.75}$ BW for KK, SF, SB and MB, respectively (Table IV.4). *Ad libitum* intake of SF (905 kJ $kg^{-0.75}$ BW) was significantly higher ($p<0.05$) than the other three breeds. No significant different was found between KK and MB (848 and 852 kJ $kg^{-0.75}$ BW, respectively) but these values were significantly higher than that of SM (701 kJ $kg^{-0.75}$ BW). The MAX_{fat}

RE based on regression equations for the corresponding *ad libitum* intake were 141, 134, 115, and 118 kJ $kg^{-0.75}$ BW, respectively for SF, KK, MB and SB. However, $TOTAL_{700}$ was the highest for SB (118 kJ $kg^{-0.75}$ BW), followed by KK (102 kJ $kg^{-0.75}$ BW), SF (105 kJ $kg^{-0.75}$ BW) and SF (88 kJ $kg^{-0.75}$ BW).

DISCUSSION

Efficiency

Except for k_{fat} of SB, the efficiency (k) values obtained in the present study for KK and SB were lower than those reported for the same breeds in Chapter II. In the present study, k_{fat}, k_{prot} and k_{total} for KK were 0.13, 0.10 and 0.22 respectively while the corresponding values reported in Chapter II were 0.18, 0.12 and 0.30 respectively. Similarly, k_{prot} (0.06) and k_{total} (0.20) for SB obtained the present study were lower than the corresponding values (0.13 and 0.25 respectively) in Chapter II. On the other hand, k_{fat} of SB in Chapter II was lower (0.12) as compared to 0.14 obtained in the present study.

The differences in k values could be due to differences in procedures used to determ[illegible] efficiencies in the two experiments. In Chapter II, k was measured at 1.5 times maintenance of a quadratic relationship (RE = a + b MEI + c MEI^2), to allow for comparison with k_f values reported by ARC (1980). Because the estimated maintenance requirement of KK and SB was 335 and 313 kJ $kg^{-0.75}$BW, respectively, k was, therefore, measured at intake level of about 5[illegible] ME $kg^{-0.75}$ BW in that study. On the other hand, k in the present study was measured at higher intake levels (between 540 to 1095 kJ ME

$kg^{-0.75}$ BW), equivalent to the upper portion of the deminishing quadratic curve in Chapter II. (Figure IV.1).

The non significant difference between k_{fat} of KK (0.13) and SB (0.14) in the present study suggested that the two breeds used ME for fat deposition at similar efficiency. This result differed from that reported in Chapter II where, KK were found to use ME more efficiently for fat deposition than SB. The difference could again be because k was measured at different level of intake in the two studies as discussed earlier. The quadratic curve of KK in Chapter II although increased more rapidly at lower intake levels (below 500 kJ $kg^{-0.75}$ BW) but diminished at a faster rate towards the higher intake range (above 500 kJ $kg^{-0.75}$ BW) and therefore explain for the lower k value than buffalo in this study (Figure IV.1).

The higher k_{fat} of KK and SB than those of SF (0.11) and MB (0.10) recorded in the present study (Table IV.3) suggested that beef breeds (KK and SB) were more efficient in fat deposition than dairy breeds (SF and MB). Garrett (1971) and Solis et al. (1988) reported similar results. Solis et al. (1988) further suggested that differences between body composition and physiological priorities between beef and dairy breeds significantly influence efficiency of energy use.

Comparisons of k_{prot} among the four breeds were less consistent than k_{fat} (Table IV.3). Although k_{prot} of SF (0.06) being the lowest among the four breeds tested, it was not significantly different from the other three breeds. A reason that could be offered to explain this inconsistency was the large variation of the protein values estimated for SF (Table IV.3). The significant difference in k_{prot} of KK and SB obtained in the present study differed with the result of Chapter II, which found that the two species did not differ significantly in efficiency of ME use for protein deposition. This inconsistency could again be due to differences in measurement procedures discussed earlier.

K_{total} of KK, SB and MB were significant among the three breeds in the order of KK (0.22), followed by SB (0.20) and MB (0.18). As in the case of k_{prot}, k_{total} of SF was the lowest (0.17), but were not significant from KK and SB. Since k_{total} was the sum of k_{fat} and k_{prot}, the inconsistency of k_{total} of SF must have been affected by its k_{prot} as discussed earlier.

Intake and Energy Retention

Most animals offered 700 kJ kg$^{-0.75}$ BW feeding level did not finish the feed as expected. Only SF ate all the feed offered at this feeding level. The average intake level measured for SB, KK and MB were 10 to 20% below the amount offered (563, 622 and 630 kJ kg$^{-0.75}$ BW, respectively for SB, KK and MB), presumably because of the eating habits of the animals. Mean *Ad libitum* intakes were found to be different among the four breeds tested, been the highest for SF (905 kJ kg$^{-0.75}$ BW), followed by MB (852 kJ kg$^{-0.75}$ BW) and KK (848 kJ kg$^{-0.75}$ BW) while SB (701 kJ kg$^{-0.75}$ BW) been the lowest. The MAX_{total} RE for the corresponding *ad libitum* intake were 141, 115, 135 and 118 kJ kg$^{-0.75}$ BW respectively for SF. MF. KK and SB. However, at a standard intake of 700 kJ kg$^{-0.75}$ BW, the maximal total RE ($TOTAL_{700}$) was highest for SB (118 kJ kg$^{-0.75}$ BW), followed by KK (102 kJ kg$^{-0.75}$ BW), SF (105 kJ kg$^{-0.75}$ BW) and MB (89 kJ kg$^{-0.75}$ BW).

These results thus indicated that MAX_{total} RE of a particular breed depended on its energetic efficiency and intake capacity. Generally, breeds that had high intake capacity performed better when feed is not a limiting factor. However, under restricted feeding, energetic efficiency is the prime factor determining the performance of a particular breed (Table IV.4).

The estimated MAX values for KK and SB (135 and 118 kJ $kg^{-0.75}$ BW per day) in this experiment were close to those estimated using quadratic equations in the earlier experiment (130 and 108 kJ $kg^{-0.75}$ BW per day, respectively for KK and SB) (see Table II.6 of Chapter II). The close similarity between the two sets of data estimated from two independent feeding trials, analysed using different procedures thus show the reliability of the data.

Table IV.1. Chemical composition and gross energy of palm kernel cake (n=4)

Dry matter (g kg^{-1} DM)	881
Crude protein (g kg^{-1} DM)	168
Neutral detergent fibre (g kg^{-1} DM)	757
Acid detergent fibre (g kg^{-1} DM)	614
Ether extract (g kg^{-1} DM)	25
Ash (g kg^{-1} DM)	45
Gross energy (MJ kg^{-1} DM)	17.9

Table IV.2 Regression coefficients and their R^2 for prediction of energy retained (RE) in fat, protein and total from ME intake (MEI) . All units in kJ $kg^{-0.75}$ per day.

	Fat	Protein	Total
Kedah Kelantan	y=-26.48+.126x (R^2=.94)	y=-27.21+.096x (R^2=.68)	y=-53.69+.222x (R^2=.91)
Sahiwal Friesian	y=-20.28+.112x (R^2=.89)	y=4.18+.061x (R^2=.33)	y=-16.10+.173x (R^2=.75)
Swamp Buffalo	y=-27.86+.137x (R^2=.89)	y=3.54+.066x (R^2=.24)	y=-24.32+.203x (R^2=.64)
Murrah Buffalo	y=-12.86+.096x (R^2=.75)	y=-22.52+.081x (R^2=.65)	y=-35.39+.178x (R^2=.80)

Model fitted was RE = $a + b$ MEI
n = 8 animals per breed

Table IV.3. Mean efficiencies of fat (k*fat*), protein (k*prot*) and total (k*total*) for Kedah Kelantan, Sahiwal x Friesian, swamp buffalo and Murrah buffalo fed palm kernel cake

	Kedah Kelantan (n=8)	Sahiwal Friesian (n=8)	Swamp buffalo (n=8)	Murrah buffalo (n=8)
k*fat*	$.126^{a}\pm.008$	$.112^{b}\pm.010$	$.137^{a}\pm.013$	$.096^{b}\pm.015$
k*prot*	$.096^{a}\pm.018$	$.061^{abc}\pm.031$	$.066^{c}\pm.031$	$.081^{b}\pm.016$
k*total*	$.222^{a}\pm.019$	$.173^{ab}\pm.027$	$.203^{b}\pm.041$	$.177^{c}\pm.024$

[a,b,c,d]: means with different superscripts in the same row are significantly different ($p<0.05$).

Table IV.4. Mean *ad libitum* intake and intake at 700 kJ ME kg$^{-0.75}$ per day, maximal energy retained (*MAX*), and retained energy at standardised intake level of 700 kJ kg$^{-0.75}$ BW (*700*) of KK cattle, Sahiwal x Friesian, Swamp Buffalo and Murrah Buffalo fed palm kernel cake. All values are in kJ kg$^{-0.75}$ BW per day.

	Kedah Kelantan (n=8)	Sahiwal Friesian (n=8)	Swamp Buffalo (n=8)	Murrah Buffalo (n=8)
Ad libitum	848.2^{b}	905.0^{a}	701.1^{c}	851.5^{b}
700 kJ ME	621.8^{b}	715.1^{a}	563.2^{c}	629.6^{b}
MAX:				
fat	80.4	81.1	68.0	68.9
protein	54.2	59.4	49.8	46.5
total	134.6	140.5	117.8	115.4
700:				
fat	61.7	58.1	68.1	54.3
protein	40.0	46.9	49.8	34.1
total	101.7	105.0	117.8	88.4

^{a,b,c}: means with different superscripts in the same row are significantly different ($p<0.05$).

Values for *MAX and 700* were estimated from regression equations of each breeds and not statistically compared.

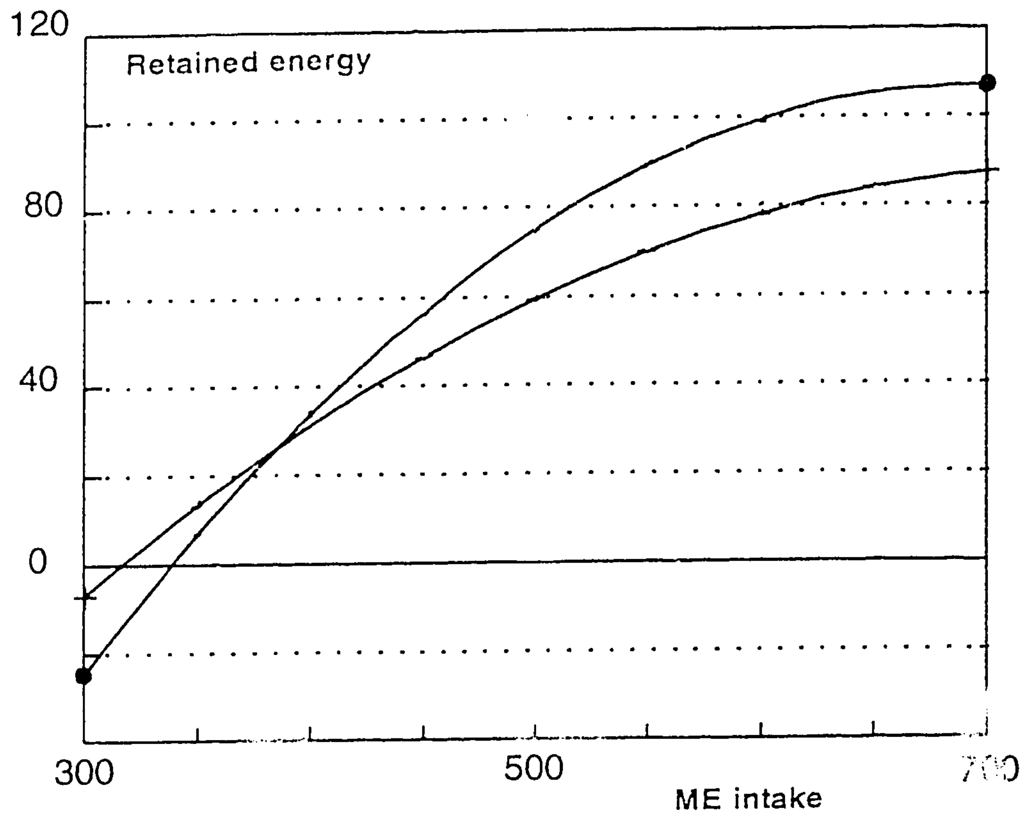

Figure IV.1 Energy retention as a function of ME intake fitted using derived equations for KK cattle (•) and swamp buffalo (+). All Values are in kJ $kg^{-0.75}$ BW per day. (Adopted from Chapter II).

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V. SYNTHESIS

The dearth of scientific information on animal requirements in the tropics has forced workers in developing countries to rely largely on published information from temperate countries when formulating feeding programmes for animal production. It is recognized that differences among animals (Frisch and Vercoe, 1977; Solis et al., 1988), feeds (Preston and Leng, 1987) and environments (NRC, 1981) affect animal performance. The feeding standard for ruminant animals in developing countries published by Kearl (1982) is an attempt to fill the deficiency but substantial effort is needed to provide guidelines for efficient feeding of livestock (Chapter I).

Realising the urgent need for livestock feeding standards in the humid tropics, the Malaysian Agricultural Research and Development Institute (MARDI) established the MARDI Feed Information Centre (MAFIC). MAFIC is an active member of the International Network of Feed Information Centres (INFIC) but concer on local needs. Scientists involved in MAFIC have been invited as con. y international agencies such as FAO to assist in livestock production programmes in ..er developing countries (including Vietnam, Bangladesh), proving the success of the center.

Tabulated feed and animal requirements such as those of ARC (1980) and NRC (1984) have been widely used over the last few decades. However, since animal growth is a dynamic process, application of these static feeding tables has constraints for predicting anim.l performance or feed requirements for growing and producing animals Simulation modelling offers new opportunities and has been applied in animal science since the 1960s (Chapter I). Simulation models of grazing systems (Kothmann et al., 1989) and individual animals (Oltjen, 1989) have advanced rapidly in the last decade, however, acceptance by by nutritionist and industry of this new approach has been slow.

Development of simulation models for animal production in tropical countries is not commensurate with needs. Livestock systems, particularly ruminant production systems, in tropical countries are extensive and under extremely variable environmental and social conditions. Since models are capable of various interactive factors characterising production systems, computer modelling offers an effective way to conduct experiments which are otherwise too expensive and time-consuming to produce by empirical experimentation. Dahlan (1989) developed one of the first widely recognised models to simulate forage yields and cattle production under oil palm plantations in Malaysia. Because of the lack of local information, almost all of the parameters used in Dhalan's sub-animal-model were based on ARC's (1980) values.

A computer model describing energy flow in individual buffalo is described in the following section. Wherever possible, research data from this thesis and data obtained under Malaysian conditions were used in its development. The main objective of the exercise was to provide a system for predicting individual performance of buffalo and KK cattle under Malaysian conditions. This model may provide new information to refine the animal sub-model in Dhalan's (1989) crop-animal integration model.

The following research finding from the previous chapters are key for the development of a dynamic computer-based feeding standard for KK cattle and swamp buffalo:

1. Indigenous Kedah-Kelantan (KK) cattle and swamp buffalo (SB) differ in energetic efficiencies for growth (Chapter II). The maintenance energy requirements for weight equilibrium (Em_{W-T}) and for energy equilibrium (Em_{RE}) for KK (338 and 335 kJ ME $kg^{-0.75}$ BW, respectively) were about 10% higher than values for SB (306 and 313 kJ ME $kg^{-0.75}$ BW, respectively).

2. The efficiencies of ME use for maintenance (k_m) and for gain (k) for KK (0.64 and 0.30, respectively) was higher than for SB (0.48 and 0.25, respectively). Because of the higher efficiency for gain, maximal energy retained (MAX) for KK (130 kJ $kg^{-0.75}$ BW) was higher than for SB (108 kJ $kg^{-0.75}$ BW).

3. Maximal food intake of both cattle and buffalo under Malaysian conditions is low, and could be the major limiting factor in expression of genetic growth potential. The average maximum intakes of the four breeds of cattle and buffalo were 700, 848, 852 and 905 kJ $kg^{-0.75}$ BW per day, respectively for SB, KK, MB and SF (Chapter IV). These values were equivalent to about 70 to 90 g DM $kg^{-0.75}$ per day and were lower than values adjusted for climatic effects suggested by NRC (1981).

M-RUMINANT MODEL

Although models should embody mechanistic concepts (France and Thornley, 1984) and represent biological function at lower levels of aggregation to improve generality. However, the more immediate needs of workers in the humid tropics are systems that will provide insight into alternative approaches to developing efficient and sustainable uses of resources. Therefore, the philosophy of developing this model for tropical ruminants, called Malaysian buffalo and cattle (M-RUMINANT), was to provide an "inhouse" model for workers in the humid tropics in general and in Malaysia in particular. The model illustrates how dynamic animal models can complement classical tabulated feed and animal requirement tables. The current version of the model is by no means complete, and needs more thorough validation. Refinement must await availability of more local data.

General Structure

M-RUMINANT was developed using the computer simulation package STELLA (High Performance Systems, USA). The model consisted of three sub-models, namely RUMEN, ENERGY and WEIGHT and has a control panel for inputs of feed type (palm kernel cake, palm kernel cake plus forage or forage), husbandry practice (close or loose feedlots or grazing), initial weight of the animal and an optional variable for work. The structural diagram of the model is shown in Figure V.1 and equations are detailed in Appendix 5.1.

Sub-Model RUMEN

RUMENFILL (kg) is a stock variable and is driven by an inflow variable, dry matter intake (DMI) and two outflow variables, namely passage of the undigested feed particles (PASSAGE) and digestion of DM (DDM) (Figure V.1). DMI (kg DM) is controlled by metabolic need (metabolic consumption, METCON), rumen distention

(RCAP) and environmental temperature (heat stress, HS). METCONs (kg DM) is determined by the metabolic demand of the animal (METDEMAND, MJ ME) divided by the metabolisable energy (ME) concentration of the feed, where ME concentration was 9.8 MJ kg^{-1} for palm kernel cake (Chapter II) and 7.5 MJ kg^{-1} for forage (Liang et al, 1988). METDEMAND is the ME required by the animal to achieve its genetic potential gain (GENEGAIN), ME requirement (MEm) and energy expenditure for work (EXPWORK), which is an optional variable for use with draught buffalo. GENEGAIN is determined by the relationship of we gain (kg d^{-1}) to body weight (BW) of the animal (kg) divided by energy value of gain (EVg). Since there are no known GENEGAIN values for buffalo and KK cattle, a rectilinear relationship between weight gain (Y, kg d^{-1}) at various BW (X, kg) was developed by assuming that the potential gain of a one year old buffalo is 0.87 kg d^{-1} (Hogan and Liang, 1991) and that growth ceases when buffalo mature at 540 kg BW (Ahman, 1981). This relationship was $Y = 1.07 - 0.002X$. Because of the lack of information, the same relationship was used for KK cattle. Similarly, EVG (MJ kg^{-1} BW) was calculated using the body composition values obtained from this thesis (Table II.3), assuming that energy values of fat and protein were 39.3 and 23.6 mJ kg^{-1}, respectively (Garrett and Hinman, 1969). The estimated EVG values are shown in Appendix 5.2).

Hot and humid environments depress intake (NRC, 1981; Leng, 1990), however, it is difficult to determine the degree of depression by environmental temperature. In this model, hot environmental temperature (heat stress, HS) affects DMI by decreasing DMI by 1% for each °C rise in environmental temperature above

(Australian Feeding Standards, 1990). The average daily environmental temperature was 32° and 28°C for dry and raining season, respectively. However, the average temperature in shaded feedlot is assumed to be relative constant at 28° C in this model. It is assummed that the rumen capacity (RCAP) of growing buffalo and KK cattle remained constant at 10 kg.

Types of feed (FEEDTYPE) affect PASSAGE and DDM via rate of rumen-turnover (k) and digestion rate (DIGRATE). There is no information on k values fed on palm kernel cake for buffalo and KK cattle. The average k values from Liang and Samiyah's experiment based on buffalo and cattle fed on 4-week and 10-week old guinea grass) were used in this model. Since M-RUMINANT runs on a daily time-step, k % h^{-1} was converted to k % d^{-1} using $k(d) = 1 - e^{-k(h)*24}$, where 0.020 h^{-1} = 0.38 d^{-1} and a value of 0.023 h^{-1} = 0.42 d^{-1} was used for KK cattle fed on palm kernel cake diet. DIGRATEs depend on feedtypes, ranged between 0.8 for palm kernel cake to 0.5 for forage based on unpublish data from studies at MARDI and that of Liang and Samiyah, 1988, showing digestible DM disappearance from nylon bag incubated in the rumen of cattle for 24 hours for palm kernel cake was about 85% and for forages of different stages of growth was 35-65%.

Sub-Model ENERGY

ENERGY is linked to RUMENFILL via DDM-MEI, at which point the kg DM unit is converted to MJ ME. The outflow variables are maintenance requirement of the animal (Em) which is defined by its basal metabolic rate (BMR), activity and an optional variable for energy expenditure for work (EXPWORK). BMR in this model is 179 kJ NE $kg^{-0.75}$ BW for buffalo and 302 kJ NE $kg^{-0.75}$ BW for KK cattle (FHP in Chapter II). Since BMR is MJ NE, it is converted to ME by dividing it by efficiency of energy use for maintenance (km), which is 0.48 and 0.64 for buffalo and KK cattle, respectively (Chapter II). ARC (1980) suggested that energy cost of standing over lying was 10 kJ kg^{-1} per day and walking 3 km and ascending 200 m in the course of 24 h would required an additional of 15% of its BMR for cattle. Based on these values, the activity cost (standing, walking, eating etc) in this sub-model was assumed to be 0.25BMR, 0.28BMR and 0.35BMR, respectively for close feedlot, loose feedlot and grazing situations.

This sub-model represents a pool of ME readily available to the animal to meet its immediate energy requirements including maintenance (Em), and work (if in operation). When total energy expenditure (Em and EXPWORK) exceeds total energy intake (MEI), energy is retrieved from the energy reserve in sub-model WEIGHT via the retained energy (RE)-GAIN loop at an efficiency of one.

Sub-Model WEIGHT

WEIGHT represents a pool of stored energy in units of net energy (MJ NE). The conversion from MJ ME to MJ NE utilised values of efficiencies of ME use for gain (k = 0.25 and 0.30, respectively for buffalo and KK cattle) as reported in (Chapter II) and EVG (refer to sub-model ENERGY for detail). Initial empty body weight (EBW) was set as 0.9 BW and EBW at any point of time (t) is EBW(t-dt) + (GAIN)*dt.

Application

The M-RUMINANT model was used to illustrate responses of buffalo and KK cattle to different feedtypes. Since most transfer values were based on growing buffalo and KK cattle between 130 to 350 kg BW from this thesis, care should be taken when simulating performance beyond these BW.

M-RUMINANT model was used to predict BW changes of yearlying buffalo and KK cattle (initital BW = 150 kg) held in pens offered either Feedtype 1 (palm kernel cake), Feedtype 2 (palm kernel cake + forage) or Feedtype 3 (forage). At the end of 365 days simulation, BW of the buffalo were 346 kg, 322 kg and 299 kg, and for KK cattle were 344 kg, 307 kg and 276 kg, respectively for Feedtypes 1, 2 and 3 and (Figure V.2). The predicted BW changes were equivalent to 0.55, 0.49 and 0.41 kg d^{-1}, for buffalo and 0.55, 0.45 kg and 0.36 kg, respectively for Feedtypes 1, 2 and 3. The predicted growth rates for both species offered Feedtypes 1 (palm kernel cake) were close to actual average values of 0.6 kg d^{-1} for buffalo and KK cattle reported by Sukri et al. (1987) and Shamsudin et al. (1987) fed on palm kernel cake based diet. The predicted daily gain value (0.45 g d^{-1}) for buffalo offered forage only was within the range of 0.35 to 0.50 kg d^{-1} reported for buffalo grazing forage under oil palms (Liang and Rahman, 1985).

Different basal metabolic rate, km, kg, EVG values were the main variables that differed between buffalo and KK cattle in this model. The predicted values for KK cattle for the three feedtypes were slightly lower than those for buffalo, particularly for forage diet. This was because of the higher metabolic demand due to higher maintenance requirments of the KK cattle resulting in lower available energy for gain. However, the various variables were interactive and attained weights that were close to actual data obtained under field conditions as discussed above.

CONCLUSION

Efficiencies of use of dietary energy and N based on net energy and net N depositions by the local cattle and buffalo obtained in this thesis are the first of such values reported for Malaysia, and possibly in the humid tropics. These values indicate differences in genetic and growth potential between ruminant animals in humid tropic and those in the temperate countries. Low maximal food intake of the local cattle and buffalo provide important information to indicate possible production constraints of these animals under humid tropical conditions.

The M-RUMINANT model developed using values from this thesis gives reliable predictions of growth rates of cattle and buffalo under different feedtypes. In addition, it provides information on interactions between the transfer functions in a dynamic sequence which is a limitation of tabulated feed and animal requirement tables such as those of ARC and NRC.

M-RUMINANT is an energy-based model. Inclusion of values on nitrogen utilisation from this thesis and those obtained under tropical conditions could further improve the the model.

The information provided in this thesis is by no means complete but added valuable research information to the existing data-base currently accumulate by MARDI for the development of suitable feeding standards for ruminant animals in Malaysia.

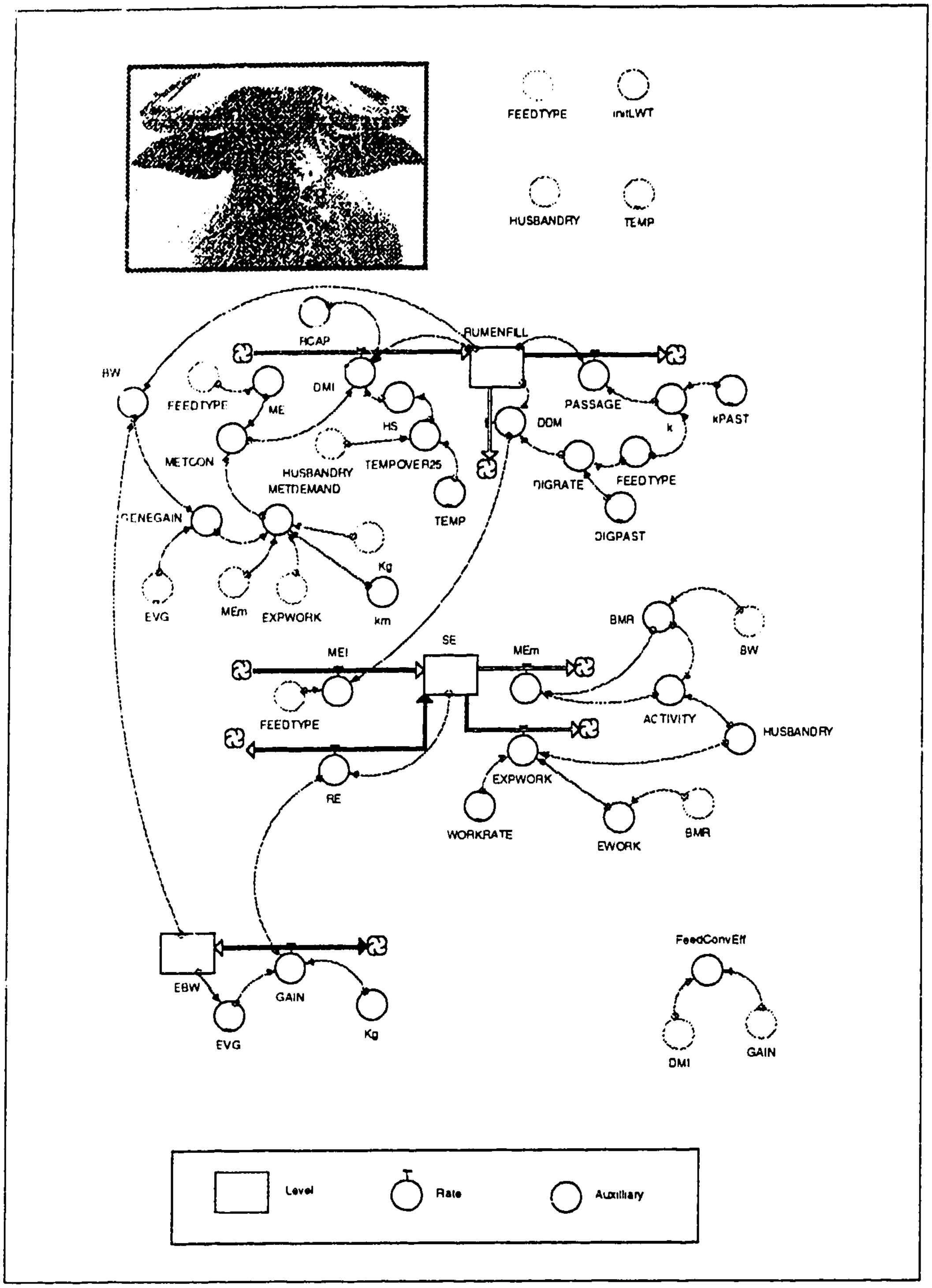

Fig. V.1. Structural diagram of M-RUMINANT in conventional systems dynamics format.

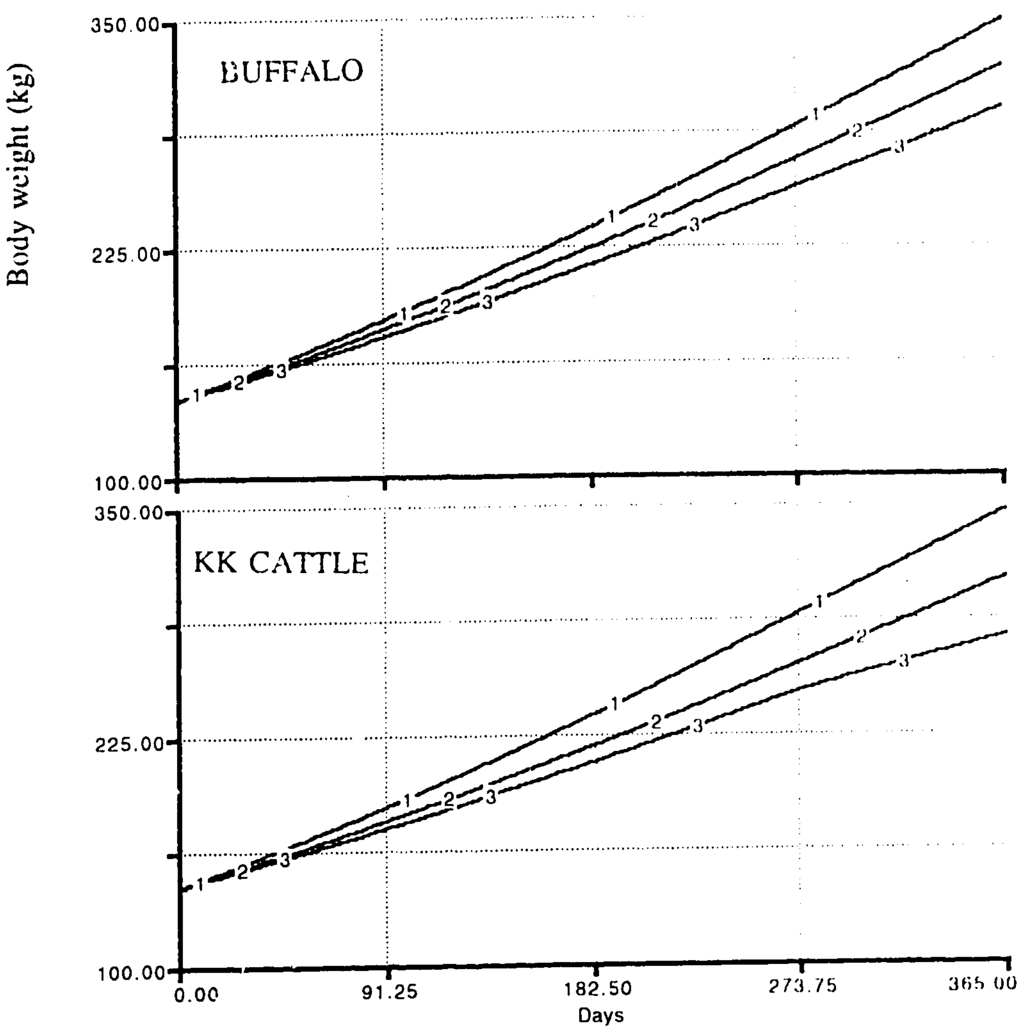

Figure V.2 Body weight changes of buffalo and KK cattle fed on palm kernel cake (1), palm kernel cake + forage (2) and forage (3) predicted by M-RUMINANT model.

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APPENDIX 1.1 (DATA FROM CHAPTER II)

Animal no. (ANI), feeding treatment (TRT 1=M, 2=1.4M, 3=1.8M, 4=ad lib), average body-weight (BW), ME intake (MEI) and energy retention as fat (FAT), prtoein (PRO) and total (TOT) of KK cattle estimated using tritiated water technique.

ANI	TRT	BW	MEI	ADG	FAT	PROT	TOTAL
1	1	130	378	2.8	19.7	11.2	30.8
1	4	161	713	14.7	102.0	59.8	161.8
1	3	200	557	11.4	74.3	45.5	119.8
1	2	237	490	7.2	43.3	29.2	72.5
2	2	169	540	8.6	30.7	34.6	65.3
2	1	183	378	1.2	1.0	4.8	5.8
2	4	206	617	12.3	35.3	49.2	84.5
2	3	242	600	7.4	30.6	29.7	60.3
3	1	163	383	5.0	14.3	1.9	16.2
3	2	188	555	9.7	29.3	38.9	68.2
3	3	226	585	11.2	36.5	44.8	81.3
3	4	263	587	7.8	43.6	31.1	74.7
4	2	176	563	8.6	86.0	34.7	120.7
4	3	210	560	8.2	50.3	32.8	83.1
4	4	235	446	6.3	35.9	25.4	61.3
4	1	250	352	1.0	-5.8	3.8	-2.0
5	2	172	527	8.3	62.9	33.3	96.2
5	4	204	636	8.9	64.7	35.7	100.4
5	3	235	599	7.4	71.6	29.8	101.4
5	1	248	362	-1.0	8.4	-2.8	5.2
6	3	190	643	12.5	65.7	50.3	116.0
6	2	234	534	6.9	50.6	32.4	83.0
6	1	-	300	-	-7.5	-0.8	-8.3
6	4	-	650	-	66.6	45.6	112.2
7	3	152	652	12.7	70.7	50.9	121.6
7	4	200	592	11.9	70.4	47.8	118.2
7	1	224	369	-1.0	14.0	-4.4	9.6
7	2	238	526	9.2	65.5	36.8	102.3
8	1	159	357	2.0	4.2	8.0	12.2
8	2	185	468	8.2	44.1	32.9	77.0
8	3	210	485	8.1	57.5	32.4	89.9
8	4	233	618	6.0	62.0	42.1	104.1

ANI	TRT	BW	MEI	ADG	FAT	PROT	TOTAL
9	3	169	589	10.3	56.0	41.4	97.4
9	2	188	342	1.4	-[illegible].8	5.5	-2.3
9	1	209	518	9.5	44.1	38.4	82.5
9	4	245	569	7.6	50.0	30.5	80.5
10	1	116	360	1.3	7.5	8.6	16.1
10	3	135	570	12.1	55.1	3.7	91.8
10	4	168	528	11.2	42.6	45.0	87.6
10	2	195	497	6.0	41.1	24.2	65.3
11	4	195	709	13.5	52.5	54.1	106.6
11	3	235	485	6.0	30.6	24.1	54.7
11	2	257	497	6.0	41.5	24.1	65.6
11	1	269	367	0.7	-0.8	3.0	2.2
12	2	148	528	7.8	44.0	31.5	75.5
12	1	164	350	3.9	6.3	15.7	22.0
12	3	186	555	8.2	30.4	33.1	63.5
12	4	212	625	8.0	51.7	32.2	83.9
13	3	147	715	12.0	74.3	48.2	122.5
13	4	188	601	11.5	61.4	45.9	107.3
13	2	210	504	4.8	42.3	19.4	61.7
13	1	219	321	0.2	-2.0	0.7	-1.3
14	4	163	630	10.8	61.0	33.9	94.9
14	1	188	371	2.6	11.5	17.4	28.9
14	2	207	474	6.7	36.3	27.0	63.3
14	3	233	593	9.8	58.2	39.3	97.5
15	4	176	519	10.8	45.4	43.2	88.6
15	3	214	431	7.2	26.5	28.7	55.2
15	1	236	345	1.6	-2.3	6.3	4.0
15	2	258	507	8.3	48.3	33.1	81.4
16	4	159	898	17.4	72.2	70.0	142.2
16	2	199	525	5.2	49.1	20.9	70.0
16	1	208	340	0.5	3.8	1.9	5.7
16	3	-	600	10.0	59.4	40.1	99.5

BW = kg, ADG = g kg-0.75 BW per day, MEI = kJ ME $kg^{-0.75}$ BW per day,
FAT, PROT & TOTAL = kJ NE $kg^{-0.75}$ BW per day .

APPENDIX 1.2 (DATA FROM CHAPTER II)

Animal no. (ANI), feeding treatment (TRT 1=M, 2=1.4M, 3=1.8M, 4=ad lib), average body-weight (BW), ME intake (MEI) and energy retention as fat (FAT), prtoein (PROT) and total (TOTAL) of swamp buffalo estimated by tritiated water technique.

ANI	TRT	BW	MEI	ADG	FAT	PROT	TOTAL	ANI	TRT	BW	MEI	ADG	FAT	PROT	TOTAL
21	3	113	474	8.0	25.5	33.0	58.5	29	3	185	744	10.4	50.2	41.7	91.9
21	2	172	542	7.0	27.0	28.2	55.2	29	4	219	407	8.9	20.4	35.9	56.3
21	1	190	369	0.9	10.7	3.5	14.2	29	-	-	300	0.8	-0.3	3.1	2.8
21	4	210	695	10.8	47.1	43.1	90.2	29	-	-	600	10.0	34.8	40.4	75.2
22	4	102	504	7.8	27.7	31.2	58.9	30	2	176	424	5.1	17.6	20.5	38.1
22	3	126	608	10.2	28.9	40.9	69.8	30	3	205	788	10.7	54.7	54.1	108.8
22	2	145	454	7.8	14.4	30.9	45.3	30	4	234	568	9.3	31.4	37.3	68.7
22	1	156	363	2.9	3.6	11.6	15.2	30	1	227	387	2.8	6.6	11.2	17.8
23	4	135	722	12.7	39.7	50.6	90.4	31	4	189	682	13.0	41.3	52.0	93.3
23	1	154	361	1.4	7.8	5.5	13.3	31	3	224	421	5.1	15.1	20.4	35.5
23	2	164	455	5.8	15.6	23.2	38.8	31	-	-	300	0.8	-0.3	3.1	2.8
23	3	194	597	10.9	33.9	43.8	77.7	31	-	-	600	10.0	34.8	40.4	75.2
24	1	168	301	0.8	0.7	3.0	3.7	32	4	178	699	1.2	35.5	48.5	84.0
24	4	184	488	2.4	33.3	28.7	62.0	32	2	197	475	6.7	15.3	26.4	41.7
24	3	204	490	7.8	23.7	31.9	55.6	32	1	216	368	3.0	0.6	11.9	12.5
24	2	230	565	5.4	31.0	37.0	68.0	32	3	238	589	9.1	33.8	36.7	70.5
25	1	123	288	0.3	-4.3	1.2	-3.1	33	3	195	684	11.8	40.5	47.5	88.0
25	2	141	563	9.9	30.7	39.9	70.6	33	1	221	36	3.0	7.9	12.2	20.1
25	3	165	508	8.0	24.0	31.9	55.9	33	2	243	398	5.3	13.8	21.2	35.0
25	4	188	552	8.5	29.6	34.0	63.6	33	4	-	600	10.0	34.9	40.4	75.3
26	2	148	441	5.7	16.7	22.9	39.6	34	3	144	649	12.7	56.7	51.0	107.7
26	1	165	406	3.8	12.8	15.1	27.9	34	4	192	702	14.4	64.1	57.9	122.0
26	4	191	574	10.1	33.2	40.6	73.8	34	2	235	466	7.0	21.1	28.3	49.4
26	3	229	592	9.8	34.1	39.6	73.7	34	1	248	387	0.6	2.9	2.6	5.5
27	3	159	670	11.5	49.9	56.0	105.9	35	2	132	540	11.6	28.0	46.5	74.5
27	4	191	438	6.0	15.2	24.1	39.3	35	4	155	469	6.6	20.1	26.4	46.5
27	-	-	300	0.8	-.3	3.1	2.8	35	-	-	300	0.8	-0.3	3.1	2.8
27	-	-	600	10.0	34.9	40.4	75.3	35	-	-	600	10.0	34.9	40.4	75.3
28	1	133	347	2.5	5.9	16.0	21.9	36	2	152	549	13.1	41.2	52.5	93.7
28	2	150	532	8.3	27.3	33.6	60.9	36	1	172	352	4.0	10.2	15.8	26.0
28	4	175	594	10.2	34.2	41.0	75.2	36	3	199	548	10.3	28.5	41.2	69.7
28	3	213	641	10.9	34.4	44.0	78.4	36	4	241	586	11.1	34.4	44.7	79.1

BW = kg, ADG = g kg-0.75 BW per day, MEI = kJ ME kg$^{-0.75}$ BW per day,
FAT, PROT & TOTAL = kJ NE kg$^{-0.75}$ BW per day .

APPENDIX 2.1 (DATA FROM CHAPTER III)

Animal no. (ANI), feeding treatment (TRT), average body-weight (BW, kg), digestible dry matter intake (DDMI, kg d^{-1}) and urinary allantoin excretion (g N d^{-1}) of Kedah-Kelantan cattle.

ANI	TRT	BW	DDMI	ALLAN	ANI	TRT	BW	DDMI	ALLAN
1	1	130	1.360	1.396	9	3	169	1.929	1.295
1	4	161	2.238	2.151	9	2	188	1.219	1.277
1	3	200	2.069	1.996	9	1	209	1.982	1.779
1	2	237	2.056	1.627	9	4	245	2.455	2.321
2	2	169	1.767	1.563	10	1	116	0.899	1.008
2	1	183	1.315	1.361	10	3	135	1.584	1.429
2	4	206	2.340	2.090	10	4	168	1.722	1.702
2	3	242	2.568	2.417	10	2	195	1.813	1.779
3	1	163	1.221	1.033	11	4	195	2.572	2.511
3	2	188	1.963	1.889	11	3	235	2.032	2.249
3	3	226	2.376	2.263	11	2	257	2.221	2.189
3	4	263	2.663	2.009	11	1	269	1.704	1.687
4	2	176	1.896	1.849	12	2	148	1.567	2.090
4	3	210	2.149	2.041	12	1	164	-	-
4	4	235	1.873	1.924	12	3	186	1.953	2.071
4	1	250	1.548	1.555	12	4	212	2.421	2.685
5	2	172	1.744	1.721	13	3	147	2.108	2.065
5	4	204	2.398	2.215	13	4	188	2.131	2.048
5	3	235	2.508	2.073	13	2	210	1.940	1.467
5	1	248	1.581	1.583	13	1	219	1.287	1.378
6	-	-	-	-	14	4	163	2.004	1.940
6	-	-	-	-	14	1	188	1.318	1.535
6	-	-	-	-	14	2	207	1.806	1.709
6	-	-	-	-	14	3	233	2.460	2.325
7	3	152	1.965	1.547	15	4	176	1.754	1.652
7	4	200	2.198	1.833	15	3	214	1.689	1.479
7	1	224	1.494	1.407	15	1	236	1.453	1.393
7	2	238	2.218	2.214	15	2	258	2.270	1.958
8	1	159	1.125	1.199	16	4	159	2.791	2.838
8	2	185	1.643	1.639	16	2	199	1.941	2.223
8	3	210	1.872	1.429	16	1	208	1.307	1.527
8	4	233	2.558	2.408	16	3	-	2.242	2.765

TRT 1= maintenance (M), TRT 2= 1.4M, TRT 3= 1.8M,
TRT 4= ad libitum feeding.

APPENDIX 2.2 (DATA FROM CHAPTER III)

Animal no. (ANI), feeding treatment (TRT), average body-weight (BW, kg), digestible dry matter intake (DDMI, kg d^{-1}) and urinary allantoin excretion (g N d^{-1}) of swamp buffalo.

ANI	TRT	BW	DDMI	ALLAN	ANI	TRT	BW	DDMI	ALLAN
21	3	113	1.146	0.670	29	3	185	2.585	1.343
21	2	172	1.793	0.991	29	4	219	1.622	0.964
21	1	190	1.317	0.717	29	-	-	2.222	1.169
21	4	210	2.661	1.378	29	-	-	-	-
22	4	102	1.138	0.578	30	2	176	1.437	0.900
22	3	126	1.590	0.819	30	3	205	2.957	1.518
22	2	145	1.319	0.746	30	4	234	2.362	1.073
22	1	156	1.117	0.650	30	1	227	1.573	0.865
23	4	135	1.986	1.060	31	4	189	2.424	1.851
23	1	154	1.102	0.643	31	3	224	1.693	1.285
23	2	164	1.450	0.808	31	-	-	-	-
23	3	194	2.156	1.140	31	-	-	-	-
24	1	168	0.988	0.510	32	4	178	2.366	1.877
24	4	184	1.698	0.882	32	2	197	1.736	1.223
24	3	204	1.840	0.765	32	1	216	1.444	1.037
24	2	230	2.312	1.009	32	3	238	2.474	1.291
25	1	123	0.749	0.647	33	3	195	2.478	1.660
25	2	141	1.597	0.865	33	1	221	1.460	1.130
25	3	165	1.627	0.893	33	2	243	1.707	0.929
25	4	188	1.943	1.040	33	4		-	-
26	2	148	1.307	0.886	34	3	144	1.881	1.011
26	1	165	1.302	0.839	34	4	192	2.512	1.121
26	4	191	2.050	1.161	34	2	235	1.944	0.950
26	3	229	2.412	1.261	34	1	248	1.680	0.916
27	3	159	2.082	0.911	35	2	132	1.461	1.052
27	4	191	1.562	0.839	35	4	155	1.432	0.888
27	-	-	-	-	35	-	-	-	-
27	-	-	-	-	35	-	-	-	-
28	1	133	0.952	0.661	36	2	152	1.653	1.252
28	2	150	1.585	0.701	36	1	172	1.169	0.705
28	4	175	1.987	0.993	36	3	199	2.022	1.077
28	3	213	2.476	1.258	36	4	241	2.488	1.297

TRT 1= maintenance (M), TRT 2= 1.4M, TRT 3= 1.8M,
TRT 4= ad libitum feeding.

APPENDIX 2.3 (DATA FROM CHAPTER III).

Body-weight (BW = kg), allantoin (ALLAN), uric acid (URIC) and hypoxanthine + xanthine (XAN) excretions during pre-fasting PF, day 1-2 of fasting (F1), day 3-4 of fasting (F2), day 5-6 of fasting (F3), day 1-2 of refeeding (RF1), day 3-4 of refeeding (RF2) and day 5-6 of refeeding (RF3) of Kedah-Kelantan cattle.

DAY	ANI	BW#	ALLAN*	URIC*	XAN*
PF	4	257	1.897	0.878	0.032
	5	248	2.175	0.557	0.031
	8	252	1.664	0.341	0.011
	14	249	1.229	0.299	0.013
F1	4	-	1.356	0.292	0.029
	5	-	1.592	0.350	0.046
	8	-	1.489	0.298	0.031
	14	-	0.979	0.229	0.021
F2	4	-	1.468	0.282	0.021
	5	-	1.036	0.280	0.008
	8	-	0.938	0.257	0.033
	14	-	0.684	0.212	0.007
F3	4	253	0.892	0.262	0.014
	5	247	0.639	0.192	0.028
	8	248	0.815	0.282	0.013
	14	249	0.619	0.223	0.013
RF1	4	-	0.600	0.140	0.012
	5	-	0.852	0.254	0.015
	8	-	0.832	0.259	0.021
	14	-	1.182	0.218	0.017
RF2	4	-	1.251	0.305	0.010
	5	-	1.503	0.401	0.004
	8	-	1.002	0.364	0.017
	14	-	0.701	0.234	0.001
RF3	4	247	1.336	0.151	0.023
	5	245	1.419	0.319	0.011
	8	243	1.235	0.151	0.019
	14	248	0.864	0.132	0.018

* = g N day^{-1}

\# BW only measured at the beginning, mid and end of experiment.

APPENDIX 2.4 (DATA FROM CHAPTER III).

Body-weight (BW = kg), allantoin (ALLAN), uric acid (URIC) and hypoxanthine + xanthine (XAN) excretion during pre-fasting PF, day 1-2 of fasting (F1), day 3-4 of fasting (F2), day 5-6 of fasting (F3), day 1-2 of refeeding (RF1), day 3-4 of refeeding (RF2) and day 5-6 of refeeding (RF3) of swamp buffalo.

DAY	ANI	BW#	ALLAN*	URIC*	XAN*
PF	21	236	0.623	0.314	0.013
	34	258	0.587	0.465	0.015
	36	272	0.663	0.334	0.016
	38	176	0.489	0.367	0.015
F1	21	-	0.801	0.274	0.020
	34	-	0.627	0.273	0.008
	36	-	0.396	0.324	0.014
	38	-	0.757	0.201	0.020
F2	21	-	0.488	0.291	0.002
	34	-	0.528	0.278	0.008
	36	-	0.880	0.579	0.041
	38	-	0.664	0.333	0.011
F3	21	229	0.571	0.238	0.026
	34	254	0.577	0.386	0.052
	36	261	0.422	0.336	0.010
	38	175	0.458	0.291	0.026
RF1	21	-	0.609	0.253	0.030
	34	-	0.407	0.208	0.018
	36	-	0.768	0.262	0.017
	38	-	0.700	0.247	0.012
RF2	21	-	0.574	0.204	0.004
	34	-	0.613	0.223	0.008
	36	-	0.656	0.268	0.004
	38	-	0.710	0.162	0.009
RF3	21	221	0.538	0.191	0.024
	34	248	0.578	0.212	0.033
	36	246	0.848	0.253	0.014
	38	173	0.829	0.212	0.023

* = g N day^{-1} # BW only measured at beginning, mid and end of experiment.

APPENDIX 3.1 (DATA FROM CHAPTER IV).

Breed (BRD), Feeding treatment (TRT), average body-weight (BW), ME intake (MEI), average daily gain (ADG), and energy retained as fat (FAT), protein (PROT) and total (TOTAL).

BRD #	TRT #	ANIM (kg)	BW	MEI*	ADG@	FAT*	PROT*	TOTAL
KK	1	52	116	869	.009	59.8	36.2	96.0
KK	2	52	146	799	.012	73.9	46.9	120.8
KK	2	53	151	1002	.018	100.7	70.3	171.0
KK	1	53	193	677	.009	57.4	36.4	93.8
KK	2	54	114	801	.017	80.9	66.1	147.0
KK	1	54	145	684	.007	59.0	39.6	98.6
KK	1	55	97	541	.009	34.6	26.2	60.8
KK	2	55	128	1001	.017	102.6	66.3	168.9
KK	1	56	119	548	.004	46.3	13.8	60.1
KK	2	56	135	763	.010	66.8	38.9	105.7
KK	1	57	123	573	.013	48.6	50.7	99.3
KK	2	57	148	763	.009	70.9	33.8	104.7
KK	2	58	82	874	.016	72.4	64.6	137.0
KK	1	58	107	653	.007	60.6	29.4	90.0
KK	2	59	116	782	.010	75.2	42.0	117.2
KK	1	59	138	624	.007	50.0	29.6	79.6
SF	2	62	208	887	.016	88.3	65.6	153.9
SF	1	62	252	706	.007	57.2	27.3	84.5
SF	1	63	166	662	.013	44.0	51.1	95.1
SF	2	63	215	1095	.015	97.6	61.6	159.2
SF	1	64	136	781	.012	63.7	49.2	112.9
SF	2	64	186	1031	.018	94.7	73.3	168.0
SF	2	65	133	946	.016	73.3	63.9	137.2
SF	1	65	163	680	.008	55.6	31.5	87.1
SF	1	66	169	765	.014	67.8	56.8	124.6
SF	2	66	221	1001	.013	94.8	51.5	146.3
SF	2	67	160	580	.014	44.2	55.3	99.5
SF	1	67	191	653	.005	55.6	21.8	77.4
SF	1	68	123	768	.019	64.8	74.5	139.3
SF	2	68	172	863	.018	87.0	74.1	161.1
SF	1	69	128	707	.011	60.4	42.8	103.2
SF	2	69	157	837	.013	73.9	53.6	127.5

BRD KK = Kedah-Kelantan cattle, SF = Sahiwal x Friesian.
TRT 1= 700 kJ $kg^{-0.75}$ BW per day, TRT 2= ad libitum feeding.
* Values are kJ $kg^{-0.75}$ BW per day. @ Values are kJ $kg^{-0.75}$ BW per day.

APPENDIX 3.2 (DATA FROM CHAPTER IV).

Breed (BRD), Feeding treatment (TRT), average body-weight (BW), ME intake (MEI), average daily gain (ADG), and energy retained as fat (FAT), protein (PROT) and total (TOTAL).

BRD #	TRT #	ANIM (kg)	BW	MEI*	ADG@	FAT*	PROT*	TOTAL*
SB	2	73	159	735	.009	70.2	37.1	107.3
SB	1	73	183	590	.008	48.0	33.9	81.9
SB	1	74	140	667	.015	62.4	61.6	124.0
SB	2	74	189	782	.014	82.9	55.6	138.5
SB	2	75	160	652	.017	72.1	69.7	141.8
SB	1	75	194	563	.010	53.9	38.0	91.9
SB	1	76	152	600	.005	46.8	18.6	65.4
SB	2	76	178	731	.011	69.5	46.1	115.6
SB	1	77	114	487	.009	41.1	35.3	76.4
SB	2	77	144	808	.013	75.7	53.6	129.3
SB	1	78	116	429	.008	26.1	32.7	58.8
SB	2	78	147	655	.016	65.7	63.1	128.8
SB	2	79	136	616	.014	57.1	55.7	112.8
SB	1	79	171	540	.009	44.3	36.5	80.8
SB	2	80	154	622	.011	59.0	43.8	102.8
SB	1	80	188	630	.010	60.6	42.2	102.8
MB	1	81	129	580	.006	40.9	24.4	65.3
MB	2	81	157	950	.014	86.0	55.8	141.7
MB	2	83	183	977	.017	63.7	64.7	128.4
MB	1	83	226	685	.006	41.8	25.3	67.1
MB	2	84	157	946	.010	76.7	40.6	117.3
MB	1	84	190	682	.009	52.9	37.0	89.9
MB	1	85	170	534	.006	34.4	25.3	59.7
MB	2	85	197	891	.014	70.7	57.9	128.6
MB	1	86	201	681	.005	53.5	18.2	71.7
MB	2	86	231	770	.008	71.5	33.8	105.3
MB	1	87	122	539	.009	44.4	34.4	78.8
MB	2	87	153	779	.010	66.9	41.9	108.8
MB	2	89	174	679	.009	50.3	32.3	82.6
MB	1	89	190	607	.003	38.6	14.3	52.9
MB	1	90	186	729	.011	64.2	45.6	109.8
MB	2	90	234	820	.013	80.5	50.6	131.1

BRD SB = swamp buffalo, MB = Murrah buffalo.
TRT 1= 700 kJ $kg^{-0.75}$ BW per day, TRT 2= ad libitum feeding.
* Values are kJ $kg^{-0.75}$ BW per day. @ Values are kg $kg^{-0.75}$ BW per day.

APPENDIX 4.2 (DATA FROM CHAPTER V)

Equations of M-RUMINANT MODEL for Swamp Buffalo

```
[] EBW(t) = EBW(t - dt) + (GAIN) * dt
   INIT EBW = .9*initLWT
   INFLOWS:
      GAIN = Max(-.3,RE*Kg/EVG)
[] RUMENFILL(t) = RUMENFILL(t - dt) + (DMI - PASSAGE - DDM) * dt
   INIT RUMENFILL = .9*RCAP
   INFLOWS:
      DMI = HS*Min(METCON,SMTH3(RCAP-RUMENFILL,3,3))
   OUTFLOWS:
      PASSAGE = RUMENFILL*k
      (K=%/d)
      DDM = RUMENFILL*DIGRATE
[] SE(t) = SE(t - dt) + (MEI - MEm - RE - EXPWORK) * dt
   INIT SE = 30
   INFLOWS:
      MEI = if FEEDTYPE=1 then DDM*17.9*.82 else IF FEEDTYPE=2 THEN DDM*17.5*.80  ELSE IF FEEDTYPE= 3 THE
      DDM*17*.79 ELSE 1
      DOCUMENT: GE Of PKC = 17.9 MJ/kg (Chapter II of thesis)
      GE  Of forage = 17 MJ/kg (Liang et al, 1988)
      Assuming ME (PKC) = .82 DE; ME forage= .79 DE

   OUTFLOWS:
      MEm = (BMR+ACTIVITY)
      RE = SE
      EXPWORK = If HUSBANDRY=4 then WORKRATE*EWORK else 0
O  ACTIVITY = If HUSBANDRY=1 then .25*BMR else if HUSBANDRY=2 then .28*BMR else .35*BMR
   DOCUMENT: Assuming activity in close feedlot = 25% BMR, Loose feedlot = 28% & grazing = 35% (ARC , 1980 cost of st
   walking, eating etc)

O  BMR = 0.179*BW^.75
   DOCUMENT: CHAPTER II OF THESIS

O  BW = RUMENFILL+EBW
O  DIGRATE = IF FEEDTYPE=1 then .85 else if FEEDTYPE=2 then .7 else if FEEDTYPE=3 then DIGPAST else .5
   DOCUMENT: DIGESTIBLE COMPONENT OF PKC = 85% DIGESTED IN 24 H (MARDI DATA)
   GRASS = 35 TO 65% DEPENDING OF AGE OF GROWTH (LIANG AND SAMIYAH, 1988)

O  EWORK = .36*BMR (15% FMR/hr)
   DOCUMENT: Assuming buffalo haul 3 to 6 carts (half tonne per cart), walk 3 km per day . Assuming energy cost = 15% B
   i.e., 36% BMR per day (Based on kearl 1980 & values from ACIAR's Draguht Animal Power Workshop values)

O  FeedConvEff = DMI/GAIN
O  FEEDTYPE = 1
   DOCUMENT: 1 = palm kernel cake (PKC)
   2 = PKC + forage
   3 = forage

O  GENEGAIN = (1.07-.002*BW)/EVG
   DOCUMENT: RELATIONSHIP OF WT GAIN AND LWT : ASSUMING POTENTIAL GAIN AT 1 YR OLD = 0.87 (HOGAN AND LIANG
   ZERO GAIN AT 540 KG (AHMAD, 1981).
   EVG CALCULATED USING FAT AND PROTEIN COMPOSITION (TABLE II.3), FAT (39.3 MJ/kg) & PROT (23.6 MJ/kg) (GARRET
   HINMAN, 1969) .
   LWT INITIAL = 137, P1 END= 168, P2 END=190, P3 END= 218, P3 END= 246 kg.

O  HS = Min(1,(100-TEMPOVER25)/100)

   DOCUMENT: (intake decreases by 1% for each T above 25C)
   (Australian Feeding Standards, 1990)
```

HUSBANDRY = 1
DOCUMENT: 1 = close feedlot
2 = loose feedlot
3 = grazing
4 = working

initLWT = 150

k = if FEEDTYPE=1 then .38 else if FEEDTYPE=2 then .38 else if FEEDTYPE=3 then kPAST else .4
DOCUMENT: Rumen turnover rate in buffalo not affected by diet quality (Liang & Samiyah, 1988; Kennedy et a, 1992).
k (%/h)= 0.023 (Liang & Samiyah, 1988) ; k (%/d) = 0.38

Kg = .25
DOCUMENT: CHAPTER II OF THESIS

km = .48
DOCUMENT: CHAPTER II OF THESIS

ME = IF FEEDTYPE=1 THEN 9.8 ELSE IF FEEDTYPE=2 THEN 9.3 ELSE IF FEEDTYPE=3 THEN 8 ELSE 7.5
DOCUMENT: ME Of Palm kernel cake = 9.8 MJ /kg DM (Chapter II of thesis)
ME Of forage = 7.5 (Liang et al. 1988)

METCON = METDEMAND/ME

METDEMAND = ((MEm+EXPWORK)/km)+(GENEGAIN/kg)

RCAP = 10

TEMPOVER25 = if HUSBANDRY=1 then 3 else Max(0,TEMP-25)
DOCUMENT: {Air temp. above 25C, 1% reduction in intake/1C above 25C}

DIGPAST = GRAPH(Time)
(0.00, 0.465), (36.5, 0.441), (73.0, 0.441), (110, 0.444), (146, 0.462), (182, 0.452), (219, 0.456),
(292, 0.429), (328, 0.438), (365, 0.459)

EVG = GRAPH(EBW)
(30.0, 5.36), (85.6, 5.60), (141, 5.89), (197, 6.26), (252, 6.59), (308, 7.13), (363, 8.00), (419, 9.74),
(530, 11.0)

kPAST = GRAPH(mod(time,365))
(0.00, 0.378), (31.8, 0.37), (63.6, 0.362), (95.5, 0.367), (127, 0.365), (159, 0.375), (191, 0.375),
0.367), (286, 0.37), (318, 0.37), (350, 0.378)

TEMP = GRAPH(TIME)
(0.00, 28.2), (33.2, 29.0), (66.4, 31.8), (99.5, 31.9), (133, 31.9), (166, 29.4), (199, 29.4), (232, 31.8),
(299, 32.0), (332, 29.6), (365, 29.3)

WORKRATE = GRAPH(mod(time,365))
(0.00, 0.125), (36.5, 0.165), (73.0, 0.28), (110, 0.285), (146, 0.21), (182, 0.13), (219, 0.125), (256, 0.21),
0.215), (328, 0.12), (365, 0.08)

APPENDIX 4.3 (DATA FROM CHAPTER V)

Estimated energy value for gain (EVG) of swamp buffalo using body compositions data from Table II.3

BW (kg)	Fat (%)	Protein (%)	Energy value (MJ)	EVG (MJ/kg)
137	5.05	16.5	805.38	5.88
167	5.48	16.6	1013.90	6.07
189	5.99	16.6	1185.35	6.27
211	6.04	16.6	1327.47	6.28
233	6.09	16.7	1475.95	6.33