Nutrient Balance and Glucose Metabolism of Female Growing, Late Pregnant and Lactating Etawah Crossbred Goats[a]

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ABSTRACT : A study involving nutrient balances and radioisotope labeling techniques was undertaken to study energy and protein metabolism, and glucose kinetics of female crossbred Etawah goats, using 12 weaned (BW 14.0 ± 2.0 kg), 12 late pregnant (BW 27.8 ± 1.8 kg) and 12 first lactation does (BW 25.0 ± 5.0 kg). Each class of animal was randomly allotted into 3 dietary treatment groups R1, R2 and R3, that received 100%, 85%, and 70% of *ad libitum* feed. The rations offered were pellets containing 21.8% CP and 19.3 MJ GE/kg, except for the lactating does who received pellets (17.2% CP and 18.9 MJ GE/kg) and fresh *Penisetum purpureum* grass. Energy and nitrogen balance studies were conducted during a two-week trial. Daily heat production (HP, estimated by the carbon dioxide entry rate technique), glucose pool and flux were measured. Equations were found for metabolizable energy (ME) and protein intake (IP) requirements for growing goats: ME (MJ/d)=1.87+0.55 RE - 0.001 ADG+0.044 RP (R^2=0.89) and IP (g/d)=48.47+2.99 RE+0.029 ADG+0.79 RP (R^2=0.90); for pregnant does: ME (MJ/d)=5.92+0.96 RE - 0.002 ADG+0.003 RP (R^2=0.99) and IP (g/d)=58.34+5.41 RE+0.625 ADG - 0.30 RP (R^2=0.98); and for lactating does: ME (MJ/d)=4.23+0.713 RE+0.003 ADG+0.006 RP+0.002 MY (R^2=0.86); IP (g/d)=84.05 - 5.36 RE+0.055 ADG - 0.16 RP+0.068 MY (R^2=0.45), where RE is retained energy (MJ/d), ADG is average daily gain in weight (g/d), RP is retained protein (g/d) and MY is milk yield (ml/d). ME and IP requirements for maintenance for growing goats were 0.46 MJ/d.kg $BW^{0.75}$ and 7.43 g/d.kg $BW^{0.75}$, respectively. Values for the pregnant and lactating does were in the same order, 0.55 MJ/d.kg $BW^{0.75}$ and 11.7 g/d.kg $BW^{0.75}$, and 0.50 MJ/d.kg $BW^{0.75}$ and 10.8 g/d.kg $BW^{0.75}$, respectively. Milk protein ranged from 3.06 to 3.5% and milk fat averaged 5.2%. Glucose metabolism in Etawah crossbred female goat is active, but glucose flux is low compared to temperate ruminant breeds which may implicate its role to support production. (*Asian-Aus. J. Anim. Sci. 2000. Vol. 13, No. 8 : 1068-1075*)

INTRODUCTION

Small ruminant production plays an important role within farming systems in the humid tropics of Southeast Asia as an income-generating activity, as a living bank for emergencies and large expenses, as a source of fertilizer for crops, as well as playing an important role in the social life of the village (Wodzicka-Tomaszewska et al., 1993). Of the factors affecting small ruminant productivity, feeding and nutrition are the most opportune method for improvement. Inadequate nutrition, consistent with a low level of production, remains a prominent feature

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of production in the Asian region. Thus, to achieve the objective of high performance, every effort must be made to improve the prevailing feeding and management practices (Devendra, 1993).

The Etawah (milk producer) and the Kacang (meat animal) are indigenous breeds of goat of Indonesia and Malaysia which are small in body size but well known for their prolificacy. Crossings between the breeds is common. Research is vital to stimulate increased production from goat with clearer focus on feeding and nutrition, and physiology (Devendra, 1993). Glucose in ruminants, where absorption from the gut is small, is equally important and its utilization is greater during pregnancy and lactation (Battaglia and Meschia, 1981; Miller et al., 1991; Freetly and Ferrell, 1997). Glucose is believed to play a key role in regulating lactation (Mepham, 1993). Gluconeogenesis (GNG) thus becomes of prime importance for the ruminant body as a whole. There is a paucity of information on indigenous ruminants of the humid tropics on the role glucose plays to support the animal's survival and production performance. The present research[*] documents some aspects of nutrient utilization in growing, pregnant and lactating crossbred Etawah goats, including glucose kinetics of this animal breed.

MATERIALS AND METHODS

Animals and feeding

Twelve female crossbred Etawah goats (6 to 8 months old, BW 14.0 ± 2.0 kg), 12 late pregnant (BW 27.8 ± 1.8 kg, 4th month pregnancy; no distinction was made between single and twin pregnancies) and 12 first lactation does (BW 25.0 ± 5.0 kg, 3rd week lactation) were used for up to two months. Each class of goat was randomly allotted into 3 dietary treatment groups (R1, R2 and R3), anticipated to consume 100%, 85%, and 70% of *ad libitum* feeding, respectively. The rations offered were pellets containing 21.8% CP (crude protein) and 19.3 MJ GE (gross energy)/kg, except for the lactating does who received pellets (17.2% CP and 18.9 MJ GE/kg) *ad libitum* plus fresh *Penisetum purpureum* grass (11.1% CP and 17.6 MJ/kg). In preliminary measurements, *ad libitum* intake was 70 g $DM/d.kg$ $BW^{0.75}$ of pellets and feeding levels were offered to the animals on this basis. The nutrient composition of the rations is presented in table 1. A one-month feed adaptation period for the growing goats was allowed before energy and N balances were measured during a two-week trial, compsising 4 days to get the animals accustomed to the metabolic cages and level of feeding, followed by 10 days total collection of excreta and unconsumed feed. Adaptation to the experimental feed for the pregnant does started from the 3rd month of pregnancy onward whereas the lactating does started to feed on the experimental ration from the last 2 weeks prior to parturition onward. Similar balance and other experimental data were collected on pregnant and lactating does as for the growing goats, during the 4th and 5th month of pregnancy and the 3rd to 4th week of lactation up to 2 months thereafter. Data on daily milk yield (MY) was obtained by twice daily hand milking following injection of oxytoxin (0.5 U). Milk protein was estimated from N content analyzed by the micro-Kjeldahl method and milk fat and lactose according to AOAC (1970). Milk energy was calculated using the heat of combustion values of 23.85, 38.50 and 16.74 kJ/g of milk protein, fat and lactose, respectively. Animals were weighed once a week and their metabolic body size was calculated. A completely randomized design with one way classification for each group was adopted. Data on average daily gain (ADG) were obtained from body weight changes during the 2 week balance period. Daily heat production (HP), glucose kinetics (glucose pool and flux) and estimation of the rate of GNG involving CO_2 fixation reactions were measured by the carbon dioxide entry rate technique (CERT) combined with single pulse labeling of glucose-2-^{3}H as previously described (Sastradipradja et al., 1976; Manik and Sastradipradja, 1989; Sastradipradja, 1992) applying the double labeling technique. The CERT measurements were completed within one week after termination of the balance trials. Measurements of body HP by CERT are uncertain if there is extrapolation of HP measurements during less than 24 h, i.e. 4 to 5 h in the present technique, to a 24 h period. Therefore, a uniform level of the daily animal's metabolic processes were attained by confining the goats in stalls indoors allowing limited physical activity only and a quiet environ. A feeding regimen offering the goats equal parts of the daily ration at 4 h intervals attempted to produce a steady state of digestion and metabolism during the time span of 24 h. Steady state condition was achieved by this procedure as evidenced from 24 h or more continuous monitoring of heart rate using Polar Sport Tester P-3000 HR Monitor (Polar Electro Oy, Finland) on a few goats.

Calculations

For the calculation of energy balance, energy loss via ruminal methane production was estimated to be 8% of GE intake (Edey, 1983) and urinary energy loss (UE) as urinary-N times 34.0 kJ/gN, which factor was computed from the difference between the *in vitro* and *in vivo* heats of oxidation of protein times 6.25 (Brody, 1945). RE (retained energy) was estimated as the difference between metabolizable energy (ME) and HP. Catabolized protein was calculated as urinary N multiplied by 6.25, while digested protein (DP) was calculated from intake protein (IP) multiplied by % protein digestibility. Retained protein (RP) was calculated as the difference between DP and catabolized protein. For lactating does RP and RE values included milk protein and energy, respectively. The glucose flux was estimated from the exponential decrease in plasma ^{3}H-glucose specific activity (SA). Glucose pool size was calculated by dividing dose of injected ^{3}H-glucose by the SA value found from extrapolation of ^{3}H-glucose SA to zero time. Glucose space of distribution was calculated by dividing pool size by plasma glucose concentration, expressed as % BW. From CERT, which involved an experimental approach of primed infusion of label ^{14}C-bicarbonate, CO_2 production rate was calculated as the ratio between rate of tracer bicarbonate infused and the plateau specific activity (SA) of CO_2 (achieved at 3 to 5 h after start of tracer infusion) and transformed into HP (Young et al., 1969). CERT also served as a basis for the calculation of the transfer quotient (TQ) between CO_2 and glucose to assess the extent of CO_2 fixation in GNG, such as from propionate, lactate, alanine and pyruvate. These precursors of glucose require the formation of oxaloacetate via intra-

Table 1. Nutrient composition of rations for experimental female Etawah crossbred goats

Nutrient		Concentrate		Grass
		Growing and pregnant	Lactating	
Dry matter	(% of feed)	88.86	89.16	15.77
Crude fiber	(% DM)	15.16	9.80	37.73
N-free extract	(% DM)	54.00	58.17	39.89
Fat	(% DM)	3.44	7.40	2.47
Crude protein	(% DM)	21.79	17.16	11.10
Ash	(% DM)	5.6	7.47	9.04
-Calcium	(% DM)	0.58	1.90	0.89
-Phosphorus	(% DM)	0.42	0.69	0.71
Energy	(MJ/kg)	19.31	18.88	17.63

mitochondrial carboxylation (CO_2 fixation) which must pass into the cytosol for phospho-enolpyruvate formation and subsequently to synthesis of glucose (Ballard et al., 1969). Since ^{14}C SA of metabolites were expressed as radioactivity per gram-atom of carbon, the theoretical maximum of T-Q from CO_2-carbon into glucose-carbon would be 16.7% (Sastradipradja et al., 1976; Manik and Sastradipradja, 1989). The rate of GNG involving CO_2 fixation was found by multiplying glucose flux by the TQ times 6.

Statistical analysis

The significance of difference between means was compared using Duncan's Multiple Range Test after ANOVA for one way classified data (Steel and Torrie, 1986). Using a stepwise multiple regression analysis of independent metabolic data (ME, RE, ADG, IP, RP and MY), equations for ME and IP requirements were developed. The computer program MINITAB/SPSS release 6.1 (1988) was used for the multiple regression procedures.

RESULTS AND DISCUSSION

The results of the digestibility and metabolism studies are presented in table 2.

Growing goats

The average intake of the *ad libitum* group (R1) of growing goats was 466 g/d DM corresponding to an intake of 3.3% BW containing 8.53 MJ/d GE and 102 g/d CP. Groups R2 and R3 consumed 74% and 65% of *ad libitum* intakes respectively instead of the respective anticipated 85% and 70%. About the same values were obtained if calculated based on protein intakes. The percentage intake levels deviated further from those anticipated if based on DE or ME intakes indicating that the digestion and subsequent metabolism of nutrients were influenced by gastro-intestinal fill and physiological response of the animal. Average ME values for R2 and R3 were 54% and 51% of that of

R1, respectively.

From the data in table 2 on performance parameters, relationships between these parameters and ME intake could be established. Empirical equations of best fit to relate these data to ME were as follows.

HP (MJ/d)=2.76+0.173 ME (MJ/d)   (r=0.40)   (1)
RE (MJ/d)=[ME (MJ/d.kg $BW^{0.75}$) - 0.46]/0.122
                                          (r=0.91)   (2)
RP (g/d)=1.28+10.355 ME (MJ/d)   (r=0.89)   (3)
IP (g/d.kg $BW^{0.75}$)=7.43+0.104 RP (g/d) (r=0.80)   (4)

Due to excitable behavior, the tropical Etawah crossbred goat might have shown higher metabolic rates and, consequently, HP values varied widely between animals, resulting in the low correlation between HP and ME (eq. 1). HP values were 1.7 times basal metabolic rate (BMR) for R1 as compared to 1.53 and 1.49 times BMR for R2 and R3, respectively. HP during 24 h could be predictable by CERT to within about 10% to 15% (McLean and Tobin, 1987; Elia et al., 1988).

To calculate nutrient requirements for survival, health and production, eq. 2 was used to calculate maintenance ME (MEm) requirement and a value of 0.46 MJ/d.kg $BW^{0.75}$ was found. Similarly, eq. 4 resulted in a value of 7.43 g/d.kg $BW^{0.75}$ for IP requirement. ME intake for R1 would be 1.48 times MEm, while for R2 and R3 the intakes were lower than maintenance, resulting in negative RE values.

The present investigation tried to incorporate independent parameters RE, ADG and RP into a mechanistic description of nutrient requirement for growth using a stepwise multiple regression analysis resulting in the following equations for ME and IP requirements:

Growing:
ME (MJ/d)=1.87+0.55 RE - 0.001 ADG+0.044 RP   (5)
      (R^2=0.89)
      (p=0.01 intercept; p=0.03 RE;

Table 2. Mean values of digestion and metabolic parameters of growing, late pregnant and lactating female Etawah crossbred goats

Nutritional parameters	Growing				Pregnant				Lactating			
	R1	R2	R3	SEM[1]	R1	R2	R3	SEM[2]	R1	R2	R3	SEM[3]
DM intake (g/d)	466[a]	342[b]	305[c]	22	939[p]	805[q]	672[r]	50	864[x]	764[y]	620[z]	38
Protein intake (g/d)	102[a]	75[b]	66[c]	7.0	142[p]	119[q]	96[r]	16.22	158[x]	152[xy]	135[y]	17
Energy intake (MJ/d)	8.53[a]	6.27[b]	5.58[c]	0.42	17.34[p]	14.48[q]	12.29[r]	0.33	15.98[x]	14.07[y]	11.38[z]	0.66
DM digestibility (%)	61	57	56	5.0	57	53	59	6.1	70	69	65	7.0
Prot. digestibility (%)	79[a]	69[b]	71[ab]	3.8	74	68	73	7.19	56	53	52	4.9
Energy digest.(%)	67[a]	52[b]	55[b]	7.6	56	52	57	4.02	59	57	68	4.8
Digestible prot. (g/d)	81[a]	52[b]	47[b]	4.5	99[p]	81[q]	70[r]	7.0	88[x]	81[y]	70[z]	6.82
ME intake (MJ/d)	4.93[a]	2.64[b]	2.52[b]	1.31	8.14[p]	6.15[q]	5.05[r]	0.63	7.85[x]	6.62[xy]	6.51[y]	1.12
ME/DE (%)	86[a]	81[b]	81[b]	0.96	82	80	81	5.9	83	82	84	2.60
HP (MJ/d)	3.62	3.25	3.17	0.45	7.23[p]	6.09[q]	4.61[r]	1.2	6.28	5.46	5.21	1.09
Catab. protein (g/d)	27.58	22.02	22.06	7.09	92.06[p]	72.1[q]	63.98[q]	15.38	56.61	55.68	54.73	6.71
RE (MJ/d)	1.31[a]	-0.61[b]	-0.65[b]	0.38	2.67[p]	0.03[q]	0.44[q]	0.21	1.57	1.16	1.30	0.62
RProtein (g/d)	53.42[a]	29.98[b]	24.94[b]	4.69	14[p]	9[q]	6[r]	1.17	31.9[x]	25.32[y]	14.27[z]	3.29
ADG (g/d)	147[a]	95[b]	57[c]	11.8	118[p]	98.4[q]	60[r]	7.14	78[z]	39[x]	23[y]	3.23
Milk yield (g/d)									594[x]	389[xy]	368[y]	158
Milk protein (g/d)									21.38[x]	14.36[y]	13.79[y]	1.47
Milk fat (g/d)									32[x]	16.25[y]	11.83[y]	4.11
Milk lactose (g/d)									30[x]	15.75[y]	15.50[y]	2.25
Milk energy (MJ/d)									2.44[x]	1.84[xy]	1.17[y]	0.76

R1=ad libitum feed intake; R2=Anticipated 90% of ad libitum intake; R3=Anticipated 80% of ad libitum intake (see text for detailed description).

Values in a row differing letter superscripts [a,b,c] for growing, [p,q,r] for pregnant and [x,y,z] for lactating goats, respectively, differ significantly at p<0.01 level.

SEM[1], SEM[2], SEM[3]=Standard error of the means due to treatment R1, R2 and R3 for female growing goats, pregnant and lactating does, respectively.

DM=Dry matter; ME=Metabolizable energy; HP=Heat production; RE=Retained energy; RProtein=Retained protein; ADG=Average daily gain.

p=0.55 ADG; p=0.04 RP)

IP (g/d)=48.47+2.99 RE+0.029 ADG+0.79 RP   (6)
(R^2=0.90)
(p=0.001 intercept; p=0.28 RE;
p=0.29 ADG; p=0.006 RP)

The fact that positive RP and ADG were obtained for R2 and R3, while on the other hand RE values were negative needs some explanation. Calculation for the case of R2 shows that RP of 29.98 g/d would be expected to be equal to an increase of 166 g body mass and a gain of 0.63 MJ of energy. RE however, is negative i.e. -0.61 MJ, thus a loss of fat has taken place equivalent to 0.63+0.61=1.24 MJ or 33 g. Body mass increase would then be 166 - 33=133 g compared to the measured ADG value of 95 g. The discrepancy may have been caused by inaccuracies of measurements.

Pregnant and lactating does

Similar to the situation with the growing goats, the actual intakes of the pregnant and lactating does (table 2) were different from the anticipated amounts consumed. Thus, R2 and R3 intakes for energy for both groups were around 87% and 72% of ad libitum intakes, respectively. For protein intakes, the values were 84% and 68% respectively for the pregnant goats, but 96% and 85% respectively for the lactating does. The lactating does had more favorable protein intakes as compared to their pregnant counterparts being 96% (R2) and 85% (R3), respectively. This phenomenon was due to the fact that although the amounts of pellets offered were rationed, all lactating does had, in addition, access to ad libitum grass feeding. The R2 and R3 groups consumed feeds with a higher protein-energy (P/E) ratio than the R1 group, 10.8 and 11.9 g/MJ versus 9.9 g/MJ. As a result R3 consumed +15%ME and +11%DP above the anticipated amount. ME intakes for R1 and R2 for the pregnant does were respectively 1.49 and 1.13 times MEm (0.46 MJ/kg BW$^{0.75}$) while for R3 it was slightly less than maintenance. For the lactating does the values were in the same order 1.53, 1.29 and 1.27 times MEm. The R1 and R2 intakes for the growing, and all groups for the pregnant and lactating does were within the range of NRC recommendations (1981).

Table 3. Parameters of glucose kinetics of female growing, late pregnant and lactating goats

Glucose kinetic parameter	Growing				Pregnant				Lactating			
	R1	R2	R3	SEM¹	R1	R2	R3	SEM²	R1	R2	R3	SEM³
Plasma concentration (mg/dl)	95.25ᵃ	84.25ᵇ	80.0ᵇ	4.7	129ᴾ	114�q	109ʳ	5.1	104	99	99	5.0
Pool size (g/animal)	4.03ᵃ	2.50ᵇ	1.70ᵇ	0.82	4.75ᴾ	3.19ᴾq	2.27q	1.6	3.30ˣ	2.22ʸ	1.96ʸ	0.43
Distribution space (% BW)	30.0ᵃ	21.50ᵇ	18.50ᵇ	5.83	29.04ᴾ	11.11q	10.0q	1.2	12.0	9.0	7.0	3.0
Glucose flux (mg/min.animal)	21.02ᵃ	12.20ᵇ	6.68ᶜ	3.60	24.63ᴾ	9.44q	5.08q	4.5	29.43ˣ	24.20ʸ	14.46ᶻ	2.90
(mg/min.kg$^{0.807}$)	2.31ᵃ	1.50ᵇ	0.83ᶜ	0.60	1.93ᴾ	0.75q	0.36q	0.72	2.15ˣ	1.88ˣʸ	1.14ʸ	0.62
Transfer quotient=TQ (%)	16.25ᵃ	13.75ᵇ	15ᶜ	1.40	18.0ᵃ	14.44ᵃᵇ	12.4ᵇ	3.5	14.73	13.63	14.75	1.95
GNG inv. CO2 fix. (mg/min.animal)	20.95ᵃ	10.20ᵇ	6.15ᶜ	3.3	28.06ᴾ	18.42ᴾ	9.0q	5.56	26.09ˣ	19.90ˣ	12.74ʸ	6.66
ME (from table 2) (MJ/d)	4.93ᵃ	2.64ᵇ	2.52ᵇ	1.31	8.14ᴾ	6.15q	5.05ʳ	0.63	7.85ˣ	6.62ˣʸ	6.51y	1.12

R1=*ad libitum* feed intake; R2=Anticipated 90% of *ad libitum* intake; R3=Anticipated 80% of *ad libitum* intake.
See text for detailed description.
Values in a row differing letter superscripts, ᵃ,ᵇ,ᶜ for growing, ᴾ,q,ʳ for pregnant and ˣ,ʸ,ᶻ for lactating goats, respectively, differ significantly at p<0.01 level.
SEM¹, SEM², SEM³=Standard error of the means due to treatment R1, R2 and R3 for female growing goats, pregnant and lactating does, respectively.
GNG inv. CO2 fix.=Gluconeogenesis involving CO_2 fixation; ME=Metabolizable energy.

Parallel to ME intakes, HP in pregnant and lactating does were elevated reaching 1.30 (R3) to 2.0 times BMR (R1) for the pregnant group and 1.59 (R3) to 1.92 times BMR (R1) for lactating does. Equations for energy and protein requirements were derived (A) and, in addition, multiple regression analysis was also performed on the data of independent metabolic and performance parameters (B).

Pregnant:
A. HP (MJ/d)=4.96+0.156 ME (MJ/d) (r=0.41)   (7)
  ME (MJ/d.kg BW$^{0.75}$)=0.55+0.088 RE (MJ/d)   (8)
  (r=0.98)
  IP (g/d.kg BW$^{0.75}$)=11.72 - 0.028 RP (g/d)   (9)
  (r=0.25)
B. ME (MJ/d)=5.92+0.96 RE - 0.002 ADG+0.003 RP
  (R^2=0.99)   (10)
  (p=0.01 intercept; p=0.001 RE;
  p=0.77 ADG; p=0.72 RP)
  IP (g/d)=58.34+5.41 RE+0.625 ADG - 0.30 RP
  (R^2=0.98)   (11)
  (p=0.007 intercept; p=0.01 RE;
  p=0.007 ADG; p=0.05 RP).

Lactating:
A. HP (MJ/d)=5.45+0.029 ME (MJ/d) (r=0.60)   (12)
  ME (MJ/d.kg BW$^{0.75}$)=0.50+0.068 RE (MJ/d)   (13)
  (r=0.87)
  IP (g/d.kg BW$^{0.75}$)=10.81 - 0.02 RP (g/d)   (14)
  (r=0.22)
B. ME (MJ/d)=4.23+0.713 RE+0.003 ADG+0.006 RP+
  0.002 MY   (15)
  (R^2=0.86); (p=0.0009 intercept; p=0.0004 RE;
  p=0.44 ADG; p=0.55 RP; p=0.10 MY);
  MY=milk yield in g/d.
  IP (g/d)=84.05 - 5.36 RE+0.055 ADG - 0.16 RP

  +0.068 MY   (16)
  (R^2=0.45); (p=0.004 intercept; p=0.11 RE;
  p=0.63 ADG; p=0.59 RP; p=0.10 MY).

Calculations show that MEm and IPm for pregnant goats were 0.55 MJ/d.kg BW$^{0.75}$ (eq. 8) and 11.7 g/d.kg BW$^{0.75}$ (eq. 9), respectively, and for the lactating does 0.50 MJ/d.kg BW$^{0.75}$ (eq. 13) and 10.8 g/d.kg BW$^{0.75}$ (eq. 14), respectively.

Summarizing the data on energy and protein metabolism of growing, pregnant and lactating goats, ME maintenance requirements of pregnant and lactating crossbred Etawah goats were 1.2 and 1.08 times MEm growing requirement, respectively, while IP maintenance requirements were in the same order 1.5 and 1.45 times IPm of growing requirement. The physiological condition of the goat has a definite effect on maintenance requirements.

The data on milk reveal that milk protein content of the crossbred Etawah goat ranges from 3.06 to 3.5%. Milk energy is around 2.35 MJ/liter, milk fat averages 5.2% and lactose 5.1%. Milk fat in this breed of animal is higher in comparison to other breeds of goat which is around 3.5% (Brody, 1945).

Role of glucose

The need for glucose is usually estimated from glucose-isotope dilution in blood, with the quotient between the rate of administration of isotopic label and the concentration of glucose label in the body glucose mass (specific activity) being used as the basis for calculation of supply to the blood through various pathways, i.e. absorbed glucose, glycogenolysis and GNG from precursors. The data on glucose kinetics are presented in table 3. Plasma glucose concentrations were relatively high for all treatment groups. Even for

the goats receiving lower planes of nutrition, GNG from precursors originating from substances in the feed offered such as propionate and glucogenic amino acids were high as judged from the TQ values which were close to the theoretical maximum. Even for the lowest value obtained with the pregnant R3 group it was 12.4% corresponding to 74% of maximum potential of GNG involving CO_2 fixation.

Comparing the values of R1, R2 and R3 treatments of all groups of goats, there were significant decreases in glucose pool size, distribution space and flux due to lowered level of feed intake. A positive correlation between each of these parameters and feed intake would be expected, although such relationship should not necessarily be with ME. Under fasting condition (zero ME intake) glucose flux and concentration would never be zero because homeostatic glucogenic mechanisms are called into operation to produce glucose from body stores and glucose precursors. In addition, ME is not a homogeneous entity but it represents an aggregation of nutrients or metabolites to take part in metabolic processes. ME could be derived from feed fibrous materials devoid of glucogenic precursors and under such situations GNG from feed sources could not take place. Consequently, glucose flux would not necessarily correlate with ME intake. Judging from the TQ values in the present experiments, the goats received rations with a liberal supply of glucose precursors and therefore a positive correlation between glucose kinetics and ME could exist.

The data on space of distribution of glucose for animals receiving lowered ME intakes demonstrated that glucose space could go lower than the theoretical value of 20% BW. Values up to 30% BW indicated distribution in a space slightly higher than extracellular fluid (Bergman, 1983), which were the cases with the growing and pregnant does receiving *ad libitum* feeding. Such values should be interpreted that part of the glucose pool resides in body cells exchanging freely with extracellular glucose (Bergman, 1983). Under normal situations such would be parenchymal cells of the liver and kidneys which have high glucogenic capacity. Active glucose production by these cells would have caused the increase in glucose pool and space of distribution. On the other hand, the present authors interpret the lowered values of space of distribution as being caused by a situation where part of extracellular fluid glucose is unidirectionally taken up by active organs preventing it from flowing back freely with the main part of the glucose pool, thus hindering them from taking part in the kinetic mechanism. The pregnant uterus and the functioning mammary gland would be the organs to be suspected to cause the observed glucose kinetic behavior in question. Due to large glucose demands of the

placenta for glycogen synthesis and the mammary gland for synthesis of milk components, glucose molecules are moving rapidly into the parenchymal cells causing a one way transfer without counter balance by a release of glucose molecules back into blood circulation.

Glucose flux is the amount of incoming glucose into the body glucose pool which is under a steady state situation equal to the amount leaving the pool. Glucose requirements for maintenance (not to be confused with the condition of MEm) are usually obtained from data with fasting animals, and under 24 to 96 h fasting a relationship for ruminants was found between glucose flux (G, mg/min.animal) and body weight (BW, kg). From data appearing in the literature for sheep and cattle, Ballard et al. (1969) found the relationship log G=0.456+0.807 log BW. The equation could be modified into an allometric expression: $G=2.86$ kg $BW^{0.807}$. Thus, beside per kg BW or per kg $BW^{0.75}$, a convenient alternative standardized unit for glucose flux would be flux per kg $BW^{0.807}$. The present data on glucose flux (table 3) revealed that the values for R1, R2 and R3 of goats under the different physiological states being studied were lower than the glucose (fasting) maintenance value when calculated using the Ballard et al. (1969) equation, even though the goats were not fasting but consuming feed larger than MEm. The values in mg/min.kg $BW^{0.807}$ were 2.31 (R1), 1.50 (R2) and 0.83 (R3) for the growing, 1.93 (R1), 0.75 (R2) and 0.36 (R3) for pregnant and 2.15 (R1), 1.88 (R2) and 1.14 (R3) for lactating does. Similar values of glucose flux in Etawah crossbred goats were observed by Manik and Sastradipradja (1989) and Sastradipradja et al. (1994). For comparison, Boekholdt (1976) reported fasting glucose flux of av. 495 mg/min for av. 465 kg cows (n=4) and av. 50.3 mg/min for av. 37.8 kg sheep (n=28), corresponding to respectively 3.5 and 2.68 mg/min.kg $BW^{0.807}$. Anand (1969) found for av. 472 kg lactating cows (n=6) before morning feeding av. flux of 793 mg/min corresponding to 5.50 mg/min.kg $BW^{0.807}$. Sastradipradja and Black (1971) reported a value of 1.97 mg/min.kg BW corresponding to 4.18 mg/min.kg $BW^{0.807}$ for non-fasting lactating Toggenburg goats. For the Javanese thin-tailed tropical single and twin pregnant and non-pregnant ewes (n=17) Sastradipradja et al. (1994) found flux values ranging from 36.5 to 75.0 mg/min, corresponding to 3.76 to 6.63 mg/min.kg $BW^{0.807}$, the ewes were fed with grass or grass supplemented with concentrate. From the present study an equation was found, that above MEm intakes for growing goats (n=12), glucose flux G (mg/min) relates to ME (MJ/d) according to G=-2.57+4.66 ME (r=0.87). Poor correlations were found for pregnant and lactating does that may be caused by reasons discussed earlier. ME seems not to be able to supply glucose precursors

especially for those receiving restricted feed intakes. Thus, from the fact that the Etawah goat demonstrated low values even at ME intakes containing glucose precursors to support production, it was concluded that the Etawah crossbred goats have low glucose flux values as compared to temperate ruminant species and in comparison also to the tropical Javanese thin-tail sheep. This trait may have implications as to the metabolic role glucose would play to support productive processes. An example of the possible implication would be the situation related to long-chain fatty acid synthesis, where glucose is needed as a source of reducing power (NADPH). In the absence of glucose that would supply NADPH by the pentose-phosphate pathway, NADPH would be provided by alternative metabolic reactions, notably from isocitric dehydro- genase reaction in the tricarboxylic acid cycle (Preston and Leng, 1987). This pathway would produce an excess of ATP which, in the lactating mammary gland could be utilized for milk (protein) synthesis. That alternative pathway may be impossible to sustain in adipose tissue where free energy could not find a sink and be liberated as body heat.

In conclusion, the present investigation with Etawah crossbred female goats revealed that feed requirements of the Etawah crossbred goat of the humid tropics follow NRC recommendation (1981), but there is a strong indication that glucose flux in this species is low in comparison to that of temperate ruminant breeds and the tropical thin-tail sheep, which warrants further investigation concerning its implication as to its role to support production. This fact is important considering the high milk fat content of this breed of goat.

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