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Nutrient requirements of goats: developed equations, other considerations and future research to improve them

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Abstract

A database of treatment mean observations from goat feeding/nutrition studies was constructed and used to develop expressions to describe nutrient requirements of goats. The ME requirement for maintenance (ME_m) was 485, 489, 580, 489 and 462 kJ/kg $BW^{0.75}$, and the ME requirement for gain (ME_g) was 13.4, 23.1, 23.1, 19.8 and 28.5 kJ/g ADG for preweaning, growing meat (≥Boer), growing dairy, growing indigenous and mature goats (indigenous and dairy), respectively. The ME_m of mature Angora goats from multiple regression analysis (at 0 tissue gain and clean fiber growth) was 473 kJ/kg $BW^{0.75}$; ME requirements for tissue gain and clean fiber growth were 37.2 and 157 kJ/g, respectively. A factorial approach with linear regression was used to determine the dietary ME requirement for lactation of 5224 kJ/kg 4% fat-corrected milk, corresponding to an efficiency of ME use for lactation of 0.59. Metabolizable protein (MP) required for maintenance (MP_m) by mature meat, dairy and indigenous goats was determined as the sum of metabolic fecal (0.0267 g/g DM intake for diets not containing appreciable browse), endogenous urinary (1.031 g/kg $BW^{0.75}$) and scurf CP losses (0.2 g/kg $BW^{0.6}$), with an assumed efficiency of MP use for maintenance protein of 1.0. Based on linear regression of MP intake against ADG, for growing goats MP_m was 3.07 g/kg $BW^{0.75}$; MP required for ADG (MP_g) was 0.290 g/g ADG for dairy and indigenous goats and 0.404 g/g ADG for meat goats. The MP requirement for lactation was 1.45 g/g milk protein, equivalent to a milk protein efficiency of 0.69. The MP_m of growing and mature Angora goats from multiple regression analysis (at 0 tissue gain and clean fiber growth) was 3.35 g/kg $BW^{0.75}$, and MP requirements for tissue gain and clean fiber growth were 0.281 and 1.65 g/g, respectively. Identified areas of research that would yield knowledge allowing development of more accurate estimates of nutrient requirements include composition of accreted and mobilized tissue, effects of stage of maturity and nutritional plane

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on maintenance energy requirements, energy expenditure due to grazing activity, conditions influencing ruminally undegraded protein and efficiencies of MP utilization.

Keywords: Goats; Nutrient requirements

1. Introduction

Goats provide meat, milk and (or) fiber to many people of the world, playing a special role in achieving food and economic securities in developing regions. In recent years demand for goat products has increased in developed countries as well, which has been accompanied by a rising number of farmers raising goats. Hence, there is need for accurate expressions of the nutrient requirements of goats. Perhaps the first prominent publication on the nutrient requirements of goats was that of NRC (1981), which has received deserved widespread usage. However, because of the continual conduct of goat nutrition and feeding research, other more recent notable nutrient requirement summaries and recommendations have been published (e.g., INRA, 1989; EAAP, 1991; AFRC, 1998; Drochner et al., 2003). In some cases, requirement expressions have been based on limited numbers of treatment means from well controlled experiments, such as with respiration calorimetry, and in some instances with extrapolation from requirements of other ruminant species. Though these reports have summarized and advanced knowledge in this area, it also seems desirable to determine nutrient requirements directly from experimentation with goats and under a broad array of conditions typical of field applications. Therefore, a database of treatment mean observations from goat feeding/nutrition studies was constructed and used to develop nutrient requirement expressions. The subsequent reports describe the procedures employed to arrive at final requirement recommendations. For brevity, these methods are not addressed here. Rather, the first objective of this report is to present the recommended nutrient requirement expressions. This is through listing the requirement expressions, as well as providing a series of 'look-up' tables. For potential users with internet access, a web-based goat nutrient requirement calculation system based on findings over-viewed in this paper is available at http://www2.luresext.edu/goats/research/nutreqgoats.html. The second objective is to suggest means of considering factors and conditions not previously thoroughly addressed in the following reports that can influence nutrient requirements, until more appropriate ones are available. The final objective is to list identified areas in which further research could lead to development of more accurate nutrient requirement expressions for goats.

2. Recommended nutrient requirement expressions

2.1. Requirement expressions

Table 1 provides the final expressions characterizing energy and protein requirements of and feed intake by goats recommended in the subsequent reports. The approach taken in the studies was empirical, with energy and protein requirements determined by regressing intake of metabolizable energy (ME) or protein (MP), or a partitioned fraction, against production, such as BW change, milk yield and (or) clean fiber growth. Hence, particular requirement expressions may not necessarily have direct relevance to the physiology of maintenance or production (e.g., milk and fiber). Rather, the expressions, taken in the context of the assumptions employed, were found capable of describing responses to changes in nutrient or energy supply.

BW expressions are on an unshrunk or fed basis, because an appropriate method of adjusting to an empty BW basis with the various experimental conditions was not available. As noted in some reports and based on conditions for most observations in the database, the nutrient requirement expressions are pertinent to animals on constant planes of nutrition near maintenance or above, in a thermoneutral and confinement (e.g., pen or stall) environment and without a signif-

Table 1
Recommended nutrient requirement expressions for goats

Item[a]	Expression	Source
Energy		
Suckling		Luo et al. (2004e)
ME_m	485 kJ/kg $BW^{0.75}$	
ME_g	13.4 kJ/g ADG	
Growing[b]		Luo et al. (2004e)
Meat		
ME_m	489 kJ/kg $BW^{0.75}$	
ME_g	23.1 kJ/g ADG	
Dairy		Luo et al. (2004e)
ME_m	580 kJ/kg $BW^{0.75}$	
ME_g	23.1 kJ/g ADG	
Indigenous		Luo et al. (2004e)
ME_m	489 kJ/kg $BW^{0.75}$	
ME_g	19.8 kJ/g ADG	
Mature[b]		
ME_m		
Method 1	(315 + 31.5 kJ/kg $BW^{0.75}$)/(k_m, or 0.503 + (0.019 × ME, MJ/kg))	AFRC (1993, 1998)
Method 2	Dairy = 501.3 kJ/kg $BW^{0.75}$, other = 422.7 kJ/kg $BW^{0.75}$	Luo et al. (2004e) and Nsahlai et al. (2004a)
ME_g	28.5 kJ/g ADG	Luo et al. (2004e)
$ME_{l\text{-}d}$		Nsahlai et al. (2004a)
Method 1	4937 kJ/kg FCM	
Method 2	5224 kJ/kg FCM	
$k_{l\text{-}d}$		Nsahlai et al. (2004a)
Method 1	0.624	
Method 2	0.589	
Angora		Luo et al. (2004d)
ME_m		
Mature		
0 ADG	533 kJ/kg $BW^{0.75}$	
0 TG and CFG	473 kJ/kg $BW^{0.75}$	
Growing		
0 ADG	560 kJ/kg $BW^{0.75}$	
0 TG and CFG	497 kJ/kg $BW^{0.75}$	
ME_g	43.2 kJ/g	
ME_{tg}	37.2 kJ/g	
ME_{fg}	157 kJ/g	
Protein		
MFCP	0.0267 g/g DM intake	Moore et al. (2004)
TPD	0.88 g/g CP intake	Moore et al. (2004)
EUCP	1.031 g/kg $BW^{0.75}$	Luo et al. (2004a)
Mature		
MP_m[c]	MFCP + EUCP + (0.2 g/kg $BW^{0.6}$)	Moore et al. (2004), Luo et al. (2004a) and NRC (1984), respectively
Growing		
MP_m[c]	3.07 g/kg $BW^{0.75}$	Luo et al. (2004c)
CP_m	MP_m/(0.64–0.80)[d]	NRC (2000)
MP_g		Luo et al. (2004c)
Dairy	0.290 g/g ADG	
Indigenous	0.290 g/g ADG	
Meat	0.404 g/g ADG	
CP_g	MP_g/(0.64–0.80)[d]	NRC (2000)

Table 1 (*Continued*)

Item[a]	Expression	Source
Lactating		
$MP_{l\text{-}d}$	1.45 g/g milk protein	Nsahlai et al. (2004b)
Angora		
MP_m		
0 ADG	$4.30\ g/kg\ BW^{0.75}$	Luo et al. (2004d)
0 TG and CFG	$3.35\ g/kg\ BW^{0.75}$	
MP_g	0.318 g/g ADG	Luo et al. (2004d)
MP_{tg}	0.281 g/g TG	Luo et al. (2004d)
MP_{fg}	1.65 g/g CFG	Luo et al. (2004d)
DMI		
Lactating	0.0964 + (0.9334 × P-DMI) − (0.1237 × ADGFCM), with P-DMI based on k = 0.653, k_m = 0.503 + (0.019 × MEC), k_g = 0.75, k_{lt} = 0.84, k_{ld} = 0.589, TEC = 23.9 MJ/kg, ME_m = 0.5013 and 0.4228 MJ/kg $BW^{0.75}$ for dairy and other goats, respectively; mobilized tissue ME used for lactation	Luo et al. (2004b)
Angora	−0.1607 + (0.8227 × P-DMI) + (0.0199 × PTCP), with P-DMI based on k = 0.525, k_m = 0.503 + (0.019 × MEC), k_{tg} = 0.006 + (0.0423 × MEC), k_{fg} = 0.151, TEC = 4.972 + (0.3274 × kg BW), ME_m = 0.473 MJ/kg $BW^{0.75}$, ME_{fg} = 157 MJ/kg; mobilized tissue ME used for fiber growth	Luo et al. (2004b)
Growing	DMI = −0.0047 + (0.9637 × P-DMI) − (70.27 × ADGBW) + (38.71 × ADGMBW) − (243.4 × $ADGMBW^2$), with P-DMI based on k = 0.634, k_m = 0.503 + (0.019 × MEC), k_g = 0.006 + (0.0423 × MEC), k_t = k_m, TEC = 23.9 MJ/kg, ME_m = 0.489, 0.580 and 0.489 MJ/kg $BW^{0.75}$ for meat, dairy and indigenous goats, respectively	Luo et al. (2004b)
Mature	DMI = −0.1241 + (0.7915 × P-DMI) + (0.0214 × PTCP) − (535.2 × ADGBW) + (247.3 × ADGMBW), with P-DMI based on k = 0.632, k_m = 0.503 + (0.019 × MEC), k_g = 0.006 + (0.0423 × MEC), k_t = k_m, TEC = 23.9 MJ/kg, ME_m = 0.462 MJ/kg $BW^{0.75}$, ME_g = 28.5 MJ/kg	Luo et al. (2004b)

ME_m: ME requirement for maintenance; ME_g: ME for whole body gain; k_m: efficiency of ME utilization for maintenance; $ME_{l\text{-}d}$: dietary ME used for lactation; $k_{l\text{-}d}$: efficiency of use of $ME_{l\text{-}d}$; ME_{tg}: ME used for non-fiber or tissue gain by Angora goats; ME_{fg}: ME used for clean mohair fiber growth by Angora goats; MFCP: metabolic fecal CP; TPD: true protein digestibility; EUCP: endogenous urinary CP; MP_m: metabolizable protein for maintenance; MP_g: MP for whole body gain; $MP_{l\text{-}d}$: dietary MP used in milk production; MP_{tg}: MP used for non-fiber or tissue gain by Angora goats; MP_{fg}: MP used for fiber gain by Angora goats; DMI: DM intake; P-DMI: initial predicted DMI; ADG:FCM: ratio of ADG:FCM (kg/kg); MEC: dietary ME concentration (MJ/kg DM); k: mean overall efficiency of ME utilization; k_g: efficiency of ME utilization for whole body gain; k_{lt}: efficiency of use of tissue energy for lactation; k_{ld}: efficiency of utilization of dietary ME for lactation; TEC: energy concentration in mobilized or accreted tissue; k_{tg}: efficiency of utilization of dietary ME for non-fiber, tissue gain by Angora goats; k_{fg}: efficiency of utilization of dietary and mobilized tissue ME for clean mohair fiber gain; k_t: efficiency of use of mobilized tissue energy for maintenance.

[a] As assumed or reported in the sources, without adjustment for gender.

[b] Growing: postweaning to 18 months of age; meat ≥ 50% Boer; dairy: Saanen, Alpine, Damascus, Norwegian, Swedish landrace and dairy crossbreed; indigenous: neither meat nor dairy, not including Angora; mature: greater than 18 months of age.

[c] Assuming an efficiency of conversion of MP to maintenance protein of 1.0 (AFRC, 1993, 1998).

[d] NRC (2000); assuming efficiency of conversion of CP to MP of 0.64 and 0.80 for diets with CP 100 and 0% degraded in the rumen, respectively.

icant parasite burden. Later, suggestions are provided for possible adjustments for conditions such as prior nutritional plane and acclimatization. However, the dataset of the study used to estimate endogenous urinary N (EUCP; Luo et al., 2004a) included a number of observations with low N intake, and it was theorized that the lower value obtained based on the regression of urinary N against total N intake is applicable to goats with N intake below maintenance, and that from the regression against apparent digestible N intake is relevant to N intakes at or above maintenance. Because metabolic fecal CP (MFCP) is most commonly expressed relative to DM ingested or excreted in feces, it would seem that the expression derived (Moore

Table 2
Estimates of metabolizable energy (ME) requirements (MJ/day) for maintenance (ME_m) and the sum of ME_m and ME required for gain (ME_g) for suckling goats

Gender	ADG (g/day)	BW (kg)								
		2	4	6	8	10	12	14	16	18
Wethers and doelings										
ME_m		0.754	1.270	1.720	2.134	2.523	2.892	3.247	3.589	3.920
$ME_m + ME_g$	50	1.424	1.939	2.390	2.804	3.193	3.562	3.917	4.259	4.590
	100	2.094	2.609	3.060	3.474	3.863	4.232	4.587	4.929	5.260
	150	2.764	3.278	3.730	4.144	4.533	4.902	5.257	5.599	5.930
	200	3.434	3.949	4.400	4.814	5.203	5.572	5.927	6.269	6.600
	250	4.104	4.619	5.070	5.484	5.873	6.242	6.597	6.939	7.270
	300	4.774	5.290	5.740	6.154	6.543	6.912	7.267	7.609	7.940
Intact males										
ME_m		0.877	1.475	1.999	2.480	2.932	3.362	3.774	4.171	4.556
$ME_m + ME_g$	50	1.547	2.145	2.669	3.150	3.602	4.032	4.444	4.841	5.226
	100	2.217	2.815	3.339	3.820	4.272	4.702	5.114	5.551	5.896
	150	2.887	3.485	4.009	4.490	4.942	5.372	5.784	6.181	6.566
	200	3.557	4.155	4.679	5.160	5.612	6.042	6.454	6.851	7.236
	250	4.227	4.825	5.349	5.830	6.282	6.712	7.124	7.521	7.906
	300	4.897	5.495	6.019	6.500	6.952	7.382	7.794	8.191	8.576

$ME_m = 485\,kJ/kg\,BW^{0.75}$ and $ME_g = 13.4\,kJ/g\,ADG$ (Luo et al., 2004e). Based on ME_g of 0.67, 1.34, 2.01, 2.68, 3.35 and 4.02 MJ/day for ADG of 50, 100, 150, 200, 250 and 300 g, respectively, and assuming ME_m for wethers and doelings and intact males is 92.5 and 107.5% of the mean, respectively (NRC, 2000).

et al., 2004) is applicable to goats regardless of nutritional plane other than diets containing appreciable browse.

2.2. Requirement tables

Recommended nutrient requirement expressions in Table 1 were used to construct other tables that can be easily used to quickly determine energy and protein requirements of and projected feed intake by goats. Tables 2 and 3 contain ME requirements for maintenance (ME_m) and gain (ME_g) for different BW and ADG of non-lactating goats, suckling or preweaning, growing and mature, respectively, based on Luo et al. (2004e) and the assumption that ME_m for wethers and doelings and intact males is 92.5 and 107.5% of means in Table 1 (NRC, 2000). Likewise, Table 4 lists ME_m requirements for mature goats based on Nsahlai et al. (2004a) and Luo et al. (2004e) assuming that ME_m of intact males is 115% of means in Table 1 (NRC, 2000) derived primarily with does and wethers. Table 5 lists ME_m for different BW of lactating goats, and Table 6 provides $ME_{l\text{-}d}$ (dietary ME used in milk production) for production of different quantities of milk varying in fat concentration based on Nsahlai et al. (2004a).

Table 7 provides MP required for maintenance (MP_m) of mature meat, dairy and indigenous goats at various BW and levels of intake as % BW, based on estimates of MFCP (Moore et al., 2003) and EUCP (Luo et al., 2004a), an equation for scurf CP loss equation of NRC (1984; scurf CP = $0.2\,g/kg\,BW^{0.6}$) and an efficiency of conversion of MP to maintenance protein of 1.0 (AFRC, 1993, 1998). Table 8 lists MP_m and MP_g requirements for growing goats of different BW and ADG (Luo et al., 2004c). Table 9 has MP needed for production of milk varying in protein content (Nsahlai et al., 2004b). In Table 10, ME and MP requirements for maintenance, tissue (non-fiber) and clean mohair fiber growth are given for Angora goats of different BW and with various rates of tissue and clean fiber gain (Luo et al., 2004d).

Tables 11–14 present estimates of voluntary DM intake (DMI) for lactating, Angora, growing and mature goats, respectively, based on one of the methods employed by Luo et al. (2004b). Estimates are listed for diets differing in ME concentration, BW and levels of

Table 3
Estimates and metabolizable energy (ME) requirements (MJ/day) for maintenance (ME_m) and the sum of ME_m and ME required for gain (ME_g) for growing goats

Biotype and gender[a]	ADG (g/day)	BW (kg)								
		15	20	25	30	35	40	45	50	55
Meat goats										
Wethers and doelings										
ME_m		3.45	4.28	5.06	5.80	6.51	7.19	7.86	8.51	9.14
$ME_m + ME_g$	50	4.60	5.43	6.21	6.95	7.66	8.35	9.01	9.66	10.29
	100	5.76	6.59	7.37	8.11	8.82	9.50	10.17	10.82	11.45
	150	6.91	7.74	8.52	9.26	9.97	10.66	11.32	11.97	12.60
	200	8.07	8.90	9.68	10.42	11.13	11.81	12.48	13.13	13.76
	250	9.22	10.05	10.83	11.57	12.28	12.97	13.63	14.28	14.91
	300	10.38	11.21	11.99	12.73	13.44	14.12	14.79	15.44	16.07
Intact males										
ME_m		4.01	4.97	5.88	6.74	7.56	8.36	9.13	9.88	10.62
$ME_m + ME_g$	50	5.16	6.13	7.03	7.89	8.72	9.52	10.29	11.04	11.77
	100	6.32	7.28	8.19	9.05	9.87	10.67	11.44	12.19	12.93
	150	7.47	8.44	9.34	10.20	11.03	11.83	12.60	13.35	14.08
	200	8.63	9.59	10.50	11.36	12.18	12.98	13.75	14.50	15.24
	250	9.78	10.75	11.65	12.51	13.34	14.14	14.91	15.66	16.39
	300	10.94	11.90	12.81	13.67	14.49	15.29	16.06	16.81	17.55
Dairy goats										
Wethers and doelings										
ME_m		4.09	5.07	6.00	6.88	7.72	8.53	9.32	10.09	10.84
$ME_m + ME_g$	50	5.24	6.23	7.15	8.03	8.88	9.69	10.48	11.24	11.99
	100	6.39	7.38	8.31	9.19	10.03	10.84	11.63	12.40	13.15
	150	7.55	8.54	9.46	10.34	11.19	12.00	12.79	13.55	14.30
	200	8.71	9.69	10.62	11.50	12.34	13.53	13.94	14.71	15.46
	250	9.86	10.85	11.77	12.65	13.50	14.31	15.10	15.86	16.61
	300	*11.02*	*12.00*	*12.93*	*13.81*	*14.65*	*15.46*	*16.25*	*17.02*	*17.77*
Intact males										
ME_m		4.75	5.90	6.97	7.99	8.97	9.92	10.83	11.72	12.59
$ME_m + ME_g$	50	5.91	7.05	8.13	9.15	10.13	11.07	11.99	12.88	13.75
	100	7.06	8.21	9.28	10.30	11.28	12.23	13.14	14.03	14.90
	150	8.22	9.36	10.44	11.46	12.44	13.38	14.30	15.19	16.06
	200	9.37	10.52	11.59	12.61	13.59	14.54	15.45	16.34	17.21
	250	10.53	11.67	12.75	13.77	14.75	15.69	16.61	17.50	18.37
	300	11.68	12.83	13.90	14.92	15.90	16.85	17.76	18.65	19.52
Indigenous goats										
Wethers and doelings										
ME_m		3.45	4.28	5.06	5.80	6.51	7.19	7.86	8.51	9.14
$ME_m + ME_g$	50	4.44	5.23	6.05	6.79	7.50	8.18	8.85	9.50	10.13
	100	5.43	6.26	7.04	7.78	8.49	9.17	9.84	10.49	11.12
	150	6.42	7.25	8.03	8.77	9.48	10.16	10.83	11.48	12.11
	200	7.41	8.24	9.02	9.76	10.47	11.15	11.82	12.47	13.10
	250	8.40	9.23	10.01	10.75	11.46	12.14	12.81	13.46	14.09
	300	*9.39*	*10.22*	*11.00*	*11.74*	*12.45*	*13.13*	*13.80*	*14.45*	*15.08*
Intact males										
ME_m		4.01	4.97	5.88	6.74	7.56	8.36	9.13	9.88	10.62
$ME_m + ME_g$	50	5.00	5.96	6.87	7.73	8.55	9.35	10.12	10.87	11.61
	100	5.99	6.95	7.86	8.72	9.54	10.34	11.11	11.86	12.60
	150	6.98	7.94	8.85	9.71	10.53	11.33	12.10	12.85	13.59
	200	7.97	8.93	9.84	10.70	11.52	12.32	13.09	13.84	14.58
	250	8.96	9.92	10.83	11.69	12.51	13.31	14.08	14.83	15.57
	300	*9.95*	*10.91*	*11.82*	*12.68*	*13.50*	*14.30*	*15.07*	*15.82*	*16.56*

$ME_m = 489$, 580 and 489 kJ/kg $BW^{0.75}$ and $ME_g = 23.1$, 23.1 and 19.8 kJ/g for meat, dairy and indigenous goats, respectively (Luo et al., 2004e); postweaning to 18 months of age. Based on ME_g of 1.115, 2.310, 3.465, 4.620, 5.775 and 6.930 MJ/day for ADG of 50, 100, 150, 200, 250 and 300 g, respectively, and assuming ME_m for wethers and doelings and intact males is 92.5 and 107.5% of the mean, respectively (NRC, 2000). Values in italics may not be employed since lower ADG is likely.

[a] Meat ≥ 50% Boer; dairy = Saanen, Alpine, Damascus, Norwegian, Swedish Landrace and dairy crossbreed; indigenous = neither meat nor dairy, not including Angora.

Table 4
Estimates of metabolizable energy (ME) requirements (MJ/day) for maintenance (ME_m) and the sum of ME_m and ME required for gain (ME_g) for mature goats

Biotype and gender[a]	ADG (g/day)	BW (kg)					
		20	30	40	50	60	70
Dairy goats							
Male castrates and does							
ME_m		4.74	6.42	7.97	9.42	10.81	12.13
$ME_m + ME_g$	20	5.31	7.00	8.54	10.00	11.38	12.70
	40	5.88	7.57	9.11	10.57	11.95	13.27
	60	6.45	8.14	9.68	11.14	12.52	13.84
	80	7.02	8.71	10.25	11.71	13.09	14.41
Intact males							
ME_m		5.45	7.39	9.17	10.84	12.43	13.95
$ME_m + ME_g$	20	6.02	7.96	9.74	11.41	12.99	14.52
	40	6.59	8.53	10.31	11.98	13.57	15.09
	60	7.16	9.10	10.87	12.55	14.14	15.66
	80	7.73	9.67	11.45	13.12	14.71	16.23
Meat and indigenous goats							
Male castrates and does							
ME_m		4.00	5.42	6.72	7.95	9.11	10.23
$ME_m + ME_g$	20	4.57	5.99	7.29	8.52	9.68	10.80
	40	5.14	6.56	7.86	9.09	10.25	11.37
	60	5.71	7.13	8.43	9.66	10.82	11.94
	80	6.28	7.70	9.00	10.23	11.39	12.51
Intact males							
ME_m		4.60	6.23	7.73	9.14	10.48	11.76
$ME_m + ME_g$	20	5.17	6.80	8.30	9.71	11.05	12.33
	40	5.74	7.37	8.87	10.28	11.62	12.90
	60	6.31	7.94	9.94	10.85	12.19	13.47
	80	6.88	8.51	10.01	11.42	12.76	14.04

ME_m = 501.3 and 422.7 kJ/kg $BW^{0.75}$ for dairy and other goats, respectively (Nsahlai et al., 2004a; Luo et al., 2004e). Over 18 months of age. An adequate number of observations was not available for meat goats (≥50% Boer); however, because of similar ME_m for growing meat and indigenous goats, requirements for mature meat and indigenous goats are assumed. Based on ME_g of 0.57, 1.14, 1.71 and 2.28 MJ/day for ADG of 20, 40, 60 and 80 g/day, respectively, and assuming ME_m for intact males 115% of that for male castrates and doelings in Table 1 (NRC, 2000).

[a] Meat ≥ 50% Boer; dairy = Saanen, Alpine, Damascus, Norwegian, Swedish Landrace and dairy crossbreed; indigenous = neither meat nor dairy, not including Angora.

production (i.e., milk yield, ADG and (or) tissue and clean mohair fiber gain). In addition, for Angora and mature goats, intake estimates are provided for diets varying in CP concentration.

3. Other considerations

In the preceding reports it was not possible to address all factors that can affect nutrient requirements of goats. Thus, below some of the most important ones are briefly discussed, with potential ways of consideration presented.

3.1. Pregnancy

NRC (1981) recommended an additional 318 kJ/kg $BW^{0.75}$ of ME in the last 2 months of gestation, and a 20% greater value was suggested for does with more than one kid. AFRC (1998) based pregnancy ME requirements on an efficiency of use of 0.133 (ARC, 1980), sheep tissue composition data, mean

Table 5
Estimates of metabolizable energy (ME) requirements (MJ/day) for maintenance (ME_m) for lactating goats

Method[a]	Biotype	Dietary ME (MJ/kg)	BW (kg)					
			20	30	40	50	60	70
1	Mean	7	5.2	7.0	8.7	10.2	11.8	13.2
		9	4.9	6.6	8.2	9.7	11.1	12.4
		11	4.6	6.2	7.7	9.2	10.5	11.8
		13	4.4	5.9	7.4	8.7	10.0	11.2
2	Dairy	Mean	4.7	6.4	8.0	9.4	10.8	12.1
	Other	Mean	4.0	5.4	6.7	8.0	9.1	10.2

[a] Method 1: $ME_m = 346.5\,kJ/kg\,BW^{0.75}$ (fasting heat production plus 10% for activity in a pen or stall environment)/k_m (efficiency of ME use for maintenance; $0.503 + (0.019 \times$ dietary ME, MJ/kg)) (AFRC, 1993, 1998). Method 2: ME_m = 501.3 and 422.7 kJ/kg $BW^{0.75}$ for dairy and other goats, respectively (Nsahlai et al., 2004a; Luo et al., 2004e).

birth weights from dairy and fiber-producing goat kid data sets and use of a Gompertz equation; requirements were presented at 3, 4 and 5 months of gestation for litter sizes of 1, 2 and 3.

Table 6
Estimates of dietary metabolizable energy (ME) requirements (MJ/day) for lactation ($ME_{l\text{-}d}$) by goats

Method[a]	Milk yield (kg)	Milk fat (%)				
		3.0	3.5	4.0	4.5	5.0
1	1	4.3	4.6	4.9	5.3	5.6
	2	8.6	9.2	9.9	10.5	11.2
	3	12.9	13.8	14.8	15.8	16.7
	4	17.2	18.5	19.8	21.0	22.3
	5	21.5	23.1	24.7	26.3	27.9
	6	25.7	27.7	29.6	31.6	*33.5*
	7	30.0	32.3	34.6	*36.8*	*39.1*
2	1	4.5	4.9	5.2	5.6	5.9
	2	9.1	9.8	10.5	11.1	11.8
	3	13.6	14.6	15.7	16.7	17.7
	4	18.2	19.5	20.9	22.3	23.6
	5	22.7	24.4	26.1	27.8	29.5
	6	27.3	29.3	31.3	33.4	*35.4*
	7	31.8	34.2	36.6	*39.0*	*41.4*

Not considering increases or decreases in BW; with increasing BW, additional required dietary ME = 23.9 kJ/g BW/0.75; with decreasing BW, tissue ME used for lactation = 23.9 kJ/g BW/0.84 (Nsahlai et al., 2004a). Values in italics may not be employed since lower yield of milk high in fat concentration is likely.

[a] $ME_{l\text{-}d}$ = (milk yield (kg) × 4.937 (Method 1) or 5.223 (Method 2) MJ/kg of 4% fat-correctedmilk) × ((1.4694 + (0.4025 × fat concentration))/3.079) (Nsahlai et al., 2004a).

Table 7
Estimates of metabolizable protein requirements for maintenance (MP_m) of mature meat, dairy and indigenous goats

DM intake (% BW)	BW (kg)						
	Unit	20	30	40	50	60	70
1	g/day	16	23	29	35	41	46
	% DM	8.1	7.6	7.2	7.0	6.8	6.6
2	g/day	22	31	40	48	57	65
	% DM	5.4	5.1	4.9	4.8	4.7	4.6
3	g/day	27	39	50	62	73	84
	% DM	4.5	4.3	4.2	4.1	4.0	4.0
4	g/day	32	47	61	75	89	103
	% DM	4.0	3.9	3.8	3.7	3.7	3.7
5	g/day	38	55	72	88	105	121
	% DM	3.8	3.7	3.6	3.5	3.5	3.5
6	g/day	43	63	82	102	121	140
	% DM	3.6	3.5	3.4	3.4	3.4	3.3

Based on metabolic fecal CP = 0.0267 × DM intake (Moore et al., 2004), endogenous urinary CP = 1.031 g/kg $BW^{0.75}$ (Luo et al., 2004a), scurf CP of 0.2 g/kg $BW^{0.6}$ (NRC, 1984) and efficiency of conversion of MP to maintenance protein of 1.0 (AFRC, 1993). CP requirements can be estimated from MP requirements and dietary concentration of rumen undegraded intake protein (UIP; dietary CP that reaches the small intestine as intact protein). For example, with diets containing 20, 40 and 60% UIP as a percentage of consumed CP, MP requirements can divided by efficiencies of conversion of CP to MP of 0.672, 0.704 and 0.736, respectively (NRC, 2000).

The NRC (1981) recommendation for the additional protein requirement due to late pregnancy was calculated from two sources, with mean values of 4.8 and 7.0 g per kg $BW^{0.75}$ of digestible protein and CP, respectively. AFRC (1998) estimated the pregnancy MP need as noted for ME and with an assumed efficiency of MP use of 0.85 (AFRC, 1992). In this regard, there are considerable differences in the efficiency assumed in different systems, such as 0.65 for beef cattle by NRC (2000) and most recently 0.33 for dairy cattle by NRC (2001).

Because requirements of ME and MP of NRC (1981) and AFRC (1998) were listed for a few specific days of gestation or large segments of late pregnancy, and (or) were based on assumed birth weights, requirements for the last five 10-day periods of gestation were estimated (Table 15) by an approach similar to that of AFRC (1998). Requirements for days 91–100 (average of 95 days) were determined

Table 8
Estimates of metabolizable protein (MP) requirements (MJ/day) for maintenance (MP_m) and the sum of MP_m and MP required for gain (MP_g) for growing goats

Biotype and gender[a]	ADG (g/day)	BW (kg)								
		15	20	25	30	35	40	45	50	55
MP_m		23	29	34	39	44	48	55	58	62
$MP_m + MP_g$										
Meat	50	44	49	55	60	64	69	74	78	82
	100	64	69	75	80	85	89	94	98	102
	150	84	90	95	100	105	109	114	118	123
	200	104	110	115	120	125	130	134	139	143
	250	124	130	135	140	145	150	154	159	163
	300	145	150	156	161	165	170	175	179	183
Dairy and indigenous	50	38	43	49	54	59	63	68	72	77
	100	52	58	63	68	73	78	82	87	91
	150	67	73	78	83	88	92	97	101	106
	200	81	87	92	97	102	107	111	116	120
	250	96	102	107	112	117	121	126	130	135
	300	110	116	121	126	131	136	140	145	149

Based on MP_m of 3.07 g/kg $BW^{0.75}$ and MP_g of 0.290 g/g ADG for dairy and indigenous goats and 0.404 g/g ADG for meat goats (Luo et al., 2004c). CP requirements can be estimated from MP requirements and dietary concentration of rumen undegraded intake protein (UIP; dietary CP that reaches the small intestine as intact protein). For example, with diets containing 20, 40 and 60% UIP as a percentage of consumed CP, MP requirements can divided by efficiencies of conversion of CP to MP of 0.672, 0.704 and 0.736, respectively (NRC, 2000).

[a] Meat ≥ 50% Boer; dairy = Saanen, Alpine, Damascus, Norwegian, Swedish Landrace and dairy crossbreed; indigenous = neither meat nor dairy, not including Angora.

Table 9
Estimates of metabolizable protein (MP; g/day) requirements of lactating goats

Milk yield (kg)	Milk protein (%)					
	2.5	3.0	3.5	4.0	4.5	5.0
1	36	44	51	58	65	73
2	73	87	102	116	131	145
3	109	131	152	174	196	218
4	145	174	203	232	261	290
5	181	218	254	290	326	363
6	218	261	305	348	392	*435*
7	254	305	355	406	*457*	*508*

Based on the MP requirement for lactation of 1.45 g/g milk protein (Nsahlai et al., 2004b). CP requirements can be estimated from MP requirements and dietary concentration of rumen undegraded intake protein (UIP; dietary CP that reaches the small intestine as intact protein). For example, with diets containing 20, 40 and 60% UIP as a percentage of consumed CP, MP requirements can divided by efficiencies of conversion of CP to MP of 0.672, 0.704 and 0.736, respectively (NRC, 2000). Values in italics may not be employed since lower yield of milk high in protein concentration is likely.

from regressions (linear and quadratic effects) of ME and MP requirements for later periods against average days of gestation. Briefly, Eq. (2) of Koong et al. (1975), derived from sheep data with single- and twin-kid litters, was used to predict fetal weight at different days of gestation based on assumed birth weights of 2, 3, 4 and 5 kg. Sheep data of Rattray et al. (1974) were used to predict fetal concentrations of protein and energy, followed by estimations of total fetal protein and energy. Fetal contributions of energy and protein to those of all pregnancy tissues (i.e., gravid uterus, fetus and mammary gland) were predicted from data of Rattray et al. (1974) as well, which allowed prediction of total energy and protein in pregnancy tissues. Efficiencies of utilization of ME and MP use for pregnancy of 0.133 (ARC, 1980) and 0.33 (NRC, 2001), respectively, were assumed.

The NRC (1981) pregnancy ME estimate for a 40 kg doe with a single kid (i.e., 5.1 MJ) is greater than most estimates in Table 15, although an increase of 20% for does with twins (6.1 MJ) resulted in somewhat better agreement. Assuming that 1 g of consumed CP yields 0.64–0.80 g of MP (NRC, 2000), the NRC

Table 10
Metabolizable energy (ME; MJ/day) and protein (MP; g/day) requirements of Angora goats

Item	BW (kg)	Tissue gain (g/day)	ME_m or MP_m	Clean fiber growth rate (g/day)				
				5	10	15	20	25
ME_m	15		3.61					
	25		5.29					
	35		6.81					
	45		8.22					
$ME_{tg} + ME_{fg}$		0		0.79	1.57	2.36	3.14	3.93
		25		1.72	2.50	3.29	4.07	4.86
		50		2.65	3.43	4.22	5.00	5.79
MP_m	15		25.5					
	25		37.5					
	35		48.2					
	45		58.2					
$MP_{tg} + MP_{fg}$		0		8.3	16.5	24.8	33.0	41.3
		25		15.3	23.5	31.8	40.0	48.3
		50		22.3	30.6	38.8	47.1	55.3

ME_m: ME requirement for maintenance; ME_{tg}: ME requirement for tissue gain; ME_{fg}: ME requirement for clean fiber growth; MP_m: MP requirement for maintenance; MP_{tg}: MP requirement for tissue gain; MP_{fg}: MP requirement for clean fiber growth. Based on $ME_m = 473\,kJ/kg\,BW^{0.75}$, $ME_{tg} = 37.2\,kJ/g\,ADG$, $ME_{fg} = 157\,kJ/g$, $MP_m = 3.35\,g/kg\,BW^{0.75}$, $MP_{tg} = 0.281\,g/g\,ADG$ and $MP_{fg} = 1.65\,g/g$ clean fiber (Luo et al., 2004d). Luo et al. (2004d) suggested that, based on findings of Luo et al. (2004e), ME_m of growing Angora goats could be estimated as 105% of listed values. ME_m for intact males can be estimated as 115% of listed values (NRC, 2000). CP requirements can be estimated from MP requirements and dietary concentration of undegraded intake protein (UIP; dietary CP that reaches the small intestine as intact protein). For example, with diets containing 20, 40 and 60% UIP as a percentage of consumed CP, MP requirements can divided by efficiencies of conversion of CP to MP of 0.672, 0.704 and 0.736, respectively (NRC, 2000).

(1981) pregnancy MP requirement is high relative to our estimates. However, there is fairly good agreement between pregnancy ME requirements in Table 15 and values of AFRC (1998). MP requirements are greater than listed by AFRC (1998) because of the different assumed efficiency of MP utilization. AFRC (1998) also presented requirements for dairy goats with a litter size of 3. Total pregnancy ME and MP requirements were 39, 37 and 33.5% greater for litters with three versus two kids in months 3, 4 and 5, respectively. These differences were used to estimate requirements for does with triplets in Table 15 (37% difference for days 111–120 and 33.5% for days 121–150).

3.2. Activity

3.2.1. Common recommendations

For energy use by goats in grazing activities, NRC (1981) recommended the addition of 25% of the suggested ME_m requirement with light activity, 50% with semi-arid rangeland and slightly hilly conditions and 75% with sparsely vegetated rangeland or mountainous transhumance pasture. AFRC (1998) suggested that energy used in activity (ME_a) for stall-fed goats was 10% of fasting heat production (10% of $315\,kJ/kg\,BW^{0.75}$), with additional costs for grazing based on $BW^{1.0}$ for horizontal movement (3.5 J/(kg BW × m)), vertical movement (28 J/(kg BW × m)), standing (0.417 kJ/(kg BW × h)) and change in position (0.26 kJ/(kg BW × number of changes)), and then application of the efficiency of ME use for maintenance. These values were based primarily on reports of ARC (1980) with sheep and of Lachica et al. (1997c) with goats on a treadmill placed at different slopes.

NRC (2000) noted the scarcity of available data concerning activity energy costs for grazing (ME_a) by beef cattle and, hence, discussed a previous Australian review. CSIRO (1990) indicated that with good grazing conditions, ME_a is 10–20% greater than the activity cost in pen or stall environments and be can be 50% greater with extensive conditions in which land

Table 11
Estimates of voluntary DM intake (kg/day) by lactating goats in a pen or stall environment

FCM (kg/day)	ADG (g/day)	30 kg BW				40 kg BW				50 kg BW				60 kg BW				70 kg BW			
		7 MJ/kg DM	9 MJ/kg DM	11 MJ/kg DM	13 MJ/kg DM	7 MJ/kg DM	9 MJ/kg DM	11 MJ/kg DM	13 MJ/kg DM	7 MJ/kg DM	9 MJ/kg DM	11 MJ/kg DM	13 MJ/kg DM	7 MJ/kg DM	9 MJ/kg DM	11 MJ/kg DM	13 MJ/kg DM	7 MJ/kg DM	9 MJ/kg DM	11 MJ/kg DM	13 MJ/kg DM
Dairy goats[a]																					
1	−150									1.49	1.24	1.08	0.97	1.67	1.39	1.21	1.09	1.84	1.53	1.33	1.20
	−100					1.45	1.20	1.04	0.93	1.64	1.36	1.18	1.05	1.82	1.51	1.31	1.17	1.99	1.65	1.43	1.28
	−50	1.41	1.16	1.00	0.89	1.61	1.32	1.14	1.01	1.80	1.48	1.27	1.13	1.98	1.62	1.40	1.25	2.15	1.77	1.52	1.36
	0	1.56	1.27	1.09	0.96	1.76	1.44	1.23	1.09	1.95	1.59	1.37	1.21	2.13	1.74	1.50	1.33	2.30	1.88	1.62	1.44
	50		1.46	1.24	1.09		1.62	1.38	1.22	2.19	1.78	1.52	1.34	2.37	1.93	1.65	1.45	2.54	2.07	1.77	1.56
	100									2.43	1.96	1.67	1.46	2.60	2.11	1.79	1.58	2.78	2.25	1.92	1.69
2	−150									2.11	1.72	1.47	1.30	2.29	1.87	1.60	1.42	2.46	2.01	1.72	1.53
	−100						1.69	1.44	1.27	2.27	1.84	1.57	1.39	2.44	1.99	1.70	1.50	2.62	2.13	1.82	1.61
	−50		1.64	1.39	1.22		1.81	1.54	1.35	2.42	1.96	1.67	1.47	2.60	2.11	1.80	1.58	2.77	2.25	1.97	1.69
	0		1.76	1.49	1.30		1.93	1.63	1.43	2.58	2.08	1.77	1.55	2.76	2.23	1.90	1.66	2.93	2.37	2.02	1.77
	50		1.64	1.43				1.79	1.56	2.82	2.27	1.92	1.68	3.00	2.42	2.05	1.79	3.17	2.56	2.17	1.90
	100										2.46	2.07	1.81		2.60	2.20	1.92		2.75	2.32	2.03
3	−150										2.21	1.87	1.64		2.35	2.00	1.75		2.50	2.12	1.86
	−100						2.17	1.84	1.60		2.33	1.97	1.72		2.48	2.10	1.84		2.62	2.22	1.95
	−50						2.30	1.94	1.69		2.45	2.07	1.81		2.60	2.20	1.92		2.74	2.32	2.03
	0						2.42	2.03	1.77		2.57	2.17	1.89		2.72	2.30	2.00		2.86	2.42	2.11
	50							2.19	1.90		2.76	2.32	2.02		2.91	2.45	2.13		3.05	2.57	2.24
	100											2.48	2.15			2.60	2.26			2.73	2.37
4	−150										2.69	2.27	1.98		2.84	2.40	2.09		2.98	2.52	2.20
	−100										2.82	2.37	2.06		2.96	2.50	2.17		3.11	2.62	2.28
	−50										2.94	2.47	2.14		3.09	2.60	2.26		3.22	2.72	2.37
	0										3.06	2.57	2.23		3.21	2.70	2.34		3.35	2.82	2.45
	50										3.25	2.72	2.36		3.40	2.85	2.47		3.54	2.97	2.58
	100											2.88	2.49			3.00	2.60			3.13	2.71
5	−150											2.67	2.31			2.80	2.43		3.47	2.92	2.54
	−100											2.77	2.40			2.90	2.51		3.59	3.02	2.62
	−50											2.87	2.48			3.00	2.60		3.72	3.12	2.71
	0											2.97	2.57			3.10	2.68		3.84	3.22	2.79
	50											3.12	2.70			3.25	2.81			3.37	2.92
	100											3.28	2.83			3.40	2.94			3.53	3.05
6	−150											3.07	2.65			3.20	2.76			3.32	2.81
	−100											3.17	2.74			3.30	2.85			3.42	2.96
	−50											3.27	2.82			3.40	2.93			3.52	3.04
	0											3.37	2.91			3.50	3.02			3.62	3.13
7	−150											3.60	3.10			3.72	3.21				
	−100											3.70	3.19			3.82	3.30				
	−50											3.80	3.27			3.92	3.38				
	0											3.90	3.36			4.02	3.47				

Table 11 (*Continued*)

FCM (kg/day)	ADG (g/day)	20 kg BW				30 kg BW				40 kg BW				50 kg BW			
		7 MJ/kg DM	9 MJ/kg DM	11 MJ/kg DM	13 MJ/kg DM	7 MJ/kg DM	9 MJ/kg DM	11 MJ/kg DM	13 MJ/kg DM	7 MJ/kg DM	9 MJ/kg DM	11 MJ/kg DM	13 MJ/kg DM	7 MJ/kg DM	9 MJ/kg DM	11 MJ/kg DM	13 MJ/kg DM
Other goats[a]																	
1	−100					1.12	0.93	0.81	0.72	1.29	1.07	0.93	0.83	1.45	1.20	1.04	0.93
	−50	1.09	0.90	0.77	0.69	1.28	1.05	0.90	0.80	1.45	1.19	1.02	0.91	1.60	1.32	1.14	1.01
	0	1.24	1.01	0.87	0.76	1.43	1.17	1.00	0.88	1.60	1.31	1.12	0.99	1.76	1.44	1.23	1.09
	50		1.20	1.02	0.89	1.67	1.35	1.15	1.01	1.84	1.49	1.27	1.11	2.00	1.62	1.38	1.22
	100						1.53	1.30	1.13		1.67	1.42	1.24		1.80	1.53	1.34
	150										1.86	1.57	1.37		1.99	1.68	1.47
2	−100						1.41	1.20	1.05	1.91	1.55	1.32	1.16	2.07	1.68	1.44	1.26
	−50						1.53	1.30	1.14	2.07	1.67	1.42	1.25	2.23	1.80	1.53	1.35
	0						1.65	1.40	1.22	2.23	1.79	1.52	1.33	2.39	1.93	1.63	1.43
	50						1.55	1.35			1.98	1.67	1.46		2.11	1.78	1.56
	100							1.48			2.17	1.82	1.58		2.30	1.94	1.69
	150											1.98	1.71			2.09	1.81
3	−100						1.90	1.60	1.39		2.04	1.72	1.50		2.17	1.83	1.60
	−50						2.02	1.70	1.48		2.16	1.82	1.58		2.29	1.93	1.68
	0							1.80	1.56		2.28	1.92	1.67		2.41	2.03	1.77
	50							1.95	1.69			2.07	1.80		2.60	2.19	1.90
	100								1.82			2.23	1.93			2.34	2.03
	150												2.05			2.49	2.16
4	−100											2.12	1.84		2.66	2.23	1.94
	−50											2.22	1.92		2.78	2.33	2.02
	0											2.32	2.01		2.90	2.43	2.11
	50												2.13			2.59	2.24
	100												2.26			2.74	2.37
	150																2.50
5	−100															2.63	2.28
	−50															2.73	2.36
	0															2.83	2.44
	50																2.57
	100																2.70

FCM = kg 4% fat-corrected milk. Based on estimates of Luo et al. (2003b). The ratio of ADG:FCM was used to adjust for variation in DM intake related to effects of stage of lactation on the ME requirement for maintenance. Therefore, knowledge of the true ME requirement for maintenance would be necessary to project these FCM from the listed DM intake estimates.

[a] Dairy = Saanen, Alpine, Damascus, Norwegian, Swedish landrace and dairy crossbreed; other = meat ($\geq$50% Boer) and indigenous (neither meat nor dairy, not including Angora).

Table 12
Estimates of voluntary DM intake (kg/day) by Angora goats in a pen or stall environment

TG	FG (g/day)	7 MJ/kg of ME				9 MJ/kg of ME				11 MJ/kg of ME				13 MJ/kg of ME			
		9% CP	12% CP	15% CP	18% CP	9% CP	12% CP	15% CP	18% CP	9% CP	12% CP	15% CP	18% CP	9% CP	12% CP	15% CP	18% CP
15 kg BW																	
0	5	0.56	0.62	0.68	0.74	0.46	0.52	0.58	0.64	0.40	0.46	0.52	0.58	0.36	0.42	0.48	0.54
	10	0.58	0.64	0.70	0.76	0.48	0.54	0.60	0.66	0.42	0.48	0.54	0.60	0.37	0.43	0.49	0.55
	15	0.61	0.67	0.73	0.79	0.50	0.56	0.62	0.68	0.43	0.49	0.55	0.61	0.39	0.45	0.51	0.57
	20	0.64	0.70	0.76	0.82	0.52	0.58	0.64	0.70	0.45	0.51	0.57	0.63	0.40	0.46	0.52	0.58
	25	0.66	0.72	0.78	0.84	0.54	0.60	0.66	0.72	0.47	0.52	0.59	0.65	0.42	0.48	0.54	0.59
25	5	0.62	0.68	0.74	0.80	0.52	0.58	0.64	0.70	0.46	0.52	0.58	0.64	0.42	0.48	0.54	0.60
	10	0.65	0.71	0.77	0.83	0.55	0.61	0.66	0.72	0.48	0.54	0.60	0.66	0.44	0.49	0.55	0.61
	15	0.67	0.73	0.79	0.85	0.57	0.63	0.69	0.75	0.50	0.56	0.62	0.68	0.45	0.51	0.57	0.63
	20	0.70	0.76	0.82	0.88	0.59	0.65	0.71	0.77	0.51	0.57	0.63	0.69	0.46	0.52	0.58	0.64
	25	0.73	0.79	0.85	0.91	0.61	0.67	0.73	0.79	0.53	0.59	0.65	0.71	0.48	0.54	0.60	0.66
50	5	0.68	0.74	0.80	0.86	0.59	0.65	0.71	0.77	0.53	0.59	0.65	0.70	0.48	0.54	0.60	0.66
	10	0.71	0.77	0.83	0.90	0.61	0.67	0.73	0.79	0.54	0.60	0.66	0.72	0.50	0.56	0.62	0.68
	15	0.74	0.80	0.86	0.92	0.63	0.69	0.75	0.81	0.56	0.62	0.68	0.74	0.51	0.57	0.63	0.69
	20					0.65	0.71	0.77	0.83	0.58	0.64	0.70	0.76	0.53	0.59	0.65	0.71
	25					0.67	0.73	0.79	0.85	0.59	0.65	0.71	0.77	0.54	0.60	0.66	0.72
100	5					0.71	0.77	0.83	0.89	0.65	0.71	0.77	0.83	0.61	0.67	0.73	0.79
	10					0.73	0.79	0.85	0.91	0.67	0.73	0.79	0.85	0.62	0.68	0.74	0.80
	15					0.75	0.81	0.87	0.93	0.68	0.74	0.80	0.86	0.64	0.70	0.76	0.82
	20					0.77	0.83	0.89	0.95	0.70	0.76	0.82	0.88	0.65	0.71	0.77	0.83
	25									0.72	0.78	0.84	0.90	0.67	0.72	0.78	0.84
25 kg BW																	
0	5	0.80	0.86	0.92	0.98	0.66	0.72	0.78	0.84	0.57	0.63	0.69	0.75	0.51	0.57	0.63	0.69
	10	0.82	0.88	0.94	1.00	0.68	0.74	0.80	0.86	0.59	0.65	0.71	0.77	0.53	0.58	0.64	0.70
	15	0.85	0.91	0.97	1.03	0.70	0.76	0.82	0.88	0.61	0.67	0.72	0.78	0.54	0.60	0.66	0.72
	20	0.88	0.94	1.00	1.06	0.72	0.78	0.84	0.90	0.62	0.68	0.74	0.80	0.55	0.61	0.67	0.73
	25	0.90	0.96	1.02	1.08	0.74	0.80	0.86	0.92	0.64	0.70	0.76	0.82	0.57	0.63	0.69	0.75
25	5	0.86	0.92	0.98	1.04	0.72	0.78	0.84	0.90	0.63	0.69	0.75	0.81	0.57	0.63	0.69	0.75
	10	0.89	0.95	1.01	0.07	0.74	0.80	0.86	0.92	0.65	0.71	0.77	0.83	0.59	0.65	0.71	0.77
	15	0.91	0.97	1.03	1.09	0.76	0.82	0.88	0.94	0.67	0.73	0.79	0.85	0.60	0.66	0.72	0.78
	20	0.94	1.00	1.06	1.12	0.78	0.84	0.90	0.96	0.68	0.74	0.80	0.86	0.62	0.68	0.74	0.80
	25	0.97	1.03	1.09	1.15	0.80	0.86	0.92	0.98	0.70	0.76	0.82	0.88	0.63	0.69	0.75	0.81
50	5	0.92	0.98	1.04	1.10	0.78	0.84	0.90	0.96	0.70	0.76	0.82	0.88	0.64	0.70	0.75	0.81
	10	0.95	1.01	1.07	1.13	0.81	0.87	0.92	0.98	0.71	0.77	0.83	0.89	0.65	0.71	0.77	0.83
	15	0.98	1.04	1.10	1.16	0.83	0.89	0.95	1.01	0.73	0.79	0.85	0.91	0.66	0.72	0.78	0.84
	20					0.85	0.91	0.97	1.03	0.75	0.81	0.87	0.93	0.68	0.74	0.80	0.86
	25					0.87	0.93	0.99	1.05	0.76	0.82	0.88	0.94	0.69	0.75	0.81	0.87
100	5					0.91	0.97	1.03	1.09	0.82	0.88	0.94	1.00	0.76	0.82	0.88	0.94
	10					0.93	0.99	1.05	1.11	0.84	0.90	0.96	1.02	0.77	0.83	0.89	0.95
	15					0.95	1.01	1.07	1.13	0.86	0.91	0.97	1.03	0.79	0.85	0.91	0.97
	20					0.97	1.03	1.09	1.15	0.87	0.93	0.99	1.05	0.80	0.86	0.92	0.98
	25					0.99	1.05	1.11	1.17	0.89	0.95	1.01	1.07	0.82	0.88	0.94	1.00

Table 12 (*Continued*)

TG	FG (g/day)	7 MJ/kg of ME				9 MJ/kg of ME				11 MJ/kg of ME				13 MJ/kg of ME			
		9% CP	12% CP	15% CP	18% CP	9% CP	12% CP	15% CP	18% CP	9% CP	12% CP	15% CP	18% CP	9% CP	12% CP	15% CP	18% CP
35 kg BW																	
0	5	1.01	1.07	1.13	1.19	0.84	0.90	0.96	1.02	0.73	0.79	0.85	0.90	0.65	0.71	0.77	0.83
	10	1.04	1.10	1.16	1.22	0.85	0.92	0.98	1.04	0.74	0.80	0.86	0.92	0.66	0.72	0.78	0.84
	15	1.07	1.13	1.19	1.25	0.88	0.94	1.00	1.06	0.76	0.82	0.88	0.94	0.68	0.74	0.80	0.86
	20	1.09	1.15	1.21	1.27	0.90	0.96	1.02	1.08	0.78	0.84	0.90	0.96	0.69	0.75	0.81	0.87
	25	1.12	1.18	1.24	1.30	0.92	0.98	1.04	1.10	0.79	0.85	0.91	0.97	0.71	0.76	0.82	0.88
25	5	1.08	1.14	1.20	1.26	0.90	0.96	1.02	1.08	0.79	0.85	0.91	0.97	0.71	0.77	0.83	0.89
	10	1.10	1.16	1.22	1.28	0.92	0.98	1.04	1.10	0.80	0.86	0.92	0.98	0.72	0.78	0.84	0.90
	15	1.13	1.19	1.25	1.31	0.94	1.00	1.06	1.12	0.82	0.88	0.94	1.00	0.74	0.80	0.86	0.92
	20	1.16	1.22	1.28	1.34	0.96	1.02	1.08	1.14	0.84	0.90	0.96	1.02	0.75	0.81	0.87	0.93
	25	1.18	1.24	1.30	1.36	0.98	1.04	1.10	1.16	0.86	0.92	0.98	1.03	0.77	0.83	0.89	0.95
50	5	1.14	1.20	1.26	1.32	0.96	1.02	1.08	1.14	0.85	0.91	0.97	1.03	0.77	0.83	0.89	0.95
	10	1.17	1.23	1.29	1.35	0.98	1.04	1.10	1.16	0.87	0.93	0.99	1.05	0.79	0.85	0.91	0.97
	15	1.19	1.25	1.31	1.37	1.00	1.06	1.12	1.18	0.88	0.94	1.00	1.06	0.80	0.86	0.92	0.98
	20					1.02	1.08	1.14	1.20	0.90	0.96	1.02	1.08	0.82	0.88	0.93	0.99
	25					1.05	1.11	1.16	1.22	0.92	0.98	1.04	1.10	0.83	0.89	0.95	1.01
100	5					1.09	1.15	1.21	1.27	0.98	1.04	1.09	1.15	0.90	0.96	1.02	1.08
	10					1.11	1.17	1.23	1.29	0.99	1.05	1.11	1.17	0.91	0.97	1.03	1.09
	15					1.13	1.19	1.25	1.31	1.01	1.07	1.13	1.19	0.93	0.99	1.05	1.10
	20					1.15	1.21	1.27	1.33	1.03	1.09	1.15	1.21	0.94	1.00	1.06	1.12
	25					1.17	1.23	1.29	1.35	1.04	1.10	1.16	1.22	0.95	1.01	1.07	1.13
45 kg BW																	
0	5	1.22	1.27	1.33	1.39	1.00	1.06	1.12	1.18	0.87	0.93	0.99	1.05	0.78	0.84	0.90	0.95
	10	1.24	1.30	1.36	1.42	1.02	1.08	1.14	1.20	0.89	0.95	1.01	1.06	0.79	0.85	0.91	0.97
	15	1.27	1.33	1.39	1.45	1.04	1.10	1.16	1.22	0.90	0.96	1.02	1.08	0.80	0.86	0.92	0.98
	20	1.29	1.35	1.41	1.47	1.07	1.13	1.18	1.24	0.92	0.98	1.04	1.10	0.82	0.88	0.94	1.00
	25	1.32	1.38	1.44	1.50	1.09	1.15	1.21	1.27	0.94	1.00	1.06	1.12	0.83	0.89	0.95	1.01
25	5	1.28	1.34	1.40	1.46	1.07	1.13	1.19	1.25	0.93	0.99	1.05	1.11	0.84	0.90	0.96	1.02
	10	1.30	1.36	1.42	1.48	1.09	1.15	1.21	1.27	0.95	1.01	1.07	1.13	0.85	0.91	0.97	1.03
	15	1.33	1.39	1.45	1.51	1.11	1.17	1.23	1.29	0.97	1.02	1.08	1.14	0.87	0.93	0.99	1.05
	20	1.36	1.42	1.48	1.54	1.13	1.19	1.25	1.31	0.98	1.04	1.10	1.16	0.88	0.94	1.00	1.06
	25	1.38	1.44	1.50	1.56	1.15	1.21	1.27	1.33	1.00	1.06	1.12	1.18	0.90	0.95	1.01	1.07
50	5	1.34	1.40	1.46	1.52	1.13	1.19	1.25	1.31	0.99	1.05	1.11	1.17	0.90	0.96	1.02	1.08
	10	1.37	1.42	1.49	1.55	1.15	1.21	1.27	1.33	1.01	1.07	1.13	1.19	0.91	0.97	1.03	1.09
	15	1.39	1.45	1.51	1.57	1.17	1.23	1.29	1.35	1.03	1.09	1.15	1.21	0.93	0.99	1.05	1.11
	20					1.19	1.25	1.31	1.37	1.04	1.10	1.16	1.22	0.94	1.00	1.06	1.12
	25					1.21	1.27	1.33	1.39	1.06	1.12	1.18	1.24	0.96	1.02	1.08	1.14
100	5					1.25	1.31	1.37	1.43	1.12	1.18	1.24	1.30	1.02	1.08	1.14	1.20
	10					1.27	1.33	1.39	1.45	1.14	1.20	1.25	1.31	1.04	1.10	1.16	1.22
	15					1.30	1.35	1.41	1.47	1.15	1.21	1.27	1.33	1.05	1.11	1.17	1.23
	20					1.32	1.38	1.44	1.49	1.17	1.23	1.29	1.35	1.07	1.13	1.19	1.25
	25					1.34	1.40	1.46	1.52	1.19	1.25	1.31	1.37	1.08	1.14	1.20	1.26

TG: tissue gain (non-fiber); FG: clean mohair fiber gain. Because of the constant TG and FG used for the initial prediction of DM intake, with subsequent adjustment for dietary CP concentration, diets low and high in CP (e.g., 9–12 and 15–18%, respectively) should be accompanied by TG and (or) FG slightly lower and greater, respectively, than listed values. Based on estimates of Luo et al. (2004b).

Table 13
Estimates of voluntary DM intake (kg/day) by growing goats in a pen or stall environment

MEC (MJ/kg)	ADG (g/day)	BW (kg)									
		10	15	20	25	30	35	40	45	50	55
Meat goats[a]											
7	0	0.38	0.51	0.63	0.75	0.86	0.97	1.07	1.17	1.27	1.36
	50	0.42	0.60	0.73	0.85	0.97	1.07	1.18	1.28	1.37	1.47
	100		0.66	0.82	0.95	1.07	1.18	1.28	1.38	1.48	1.57
	150			0.89	1.03	1.16	1.27	1.38	1.48	1.57	1.67
9	0	0.31	0.42	0.52	0.62	0.71	0.80	0.88	0.96	1.04	1.12
	50	0.36	0.50	0.62	0.72	0.81	0.90	0.99	1.07	1.15	1.23
	100	0.37	0.57	0.70	0.81	0.91	1.00	1.09	1.17	1.25	1.33
	150	0.34	0.61	0.77	0.90	1.00	1.10	1.19	1.27	1.35	1.43
	200		0.63	0.83	0.97	1.09	1.19	1.28	1.37	1.45	1.53
	250			0.87	1.04	1.16	1.27	1.37	1.46	1.54	1.62
	300			0.90	1.09	1.23	1.35	1.45	1.54	1.63	1.71
11	0	0.27	0.36	0.45	0.53	0.61	0.69	0.76	0.83	0.90	0.97
	50	0.31	0.45	0.55	0.64	0.72	0.79	0.87	0.94	1.01	1.07
	100	0.32	0.51	0.63	0.73	0.82	0.89	0.97	1.04	1.11	1.18
	150	0.30	0.55	0.70	0.81	0.91	0.99	1.07	1.14	1.21	1.28
	200		0.57	0.76	0.89	0.99	1.08	1.16	1.23	1.30	1.37
	250			0.80	0.95	1.06	1.16	1.25	1.32	1.40	1.47
	300			0.83	1.00	1.13	1.24	1.33	1.41	1.49	1.56
13	0	0.24	0.32	0.40	0.47	0.54	0.61	0.68	0.74	0.80	0.86
	50	0.29	0.41	0.50	0.58	0.65	0.72	0.78	0.85	0.91	0.97
	100	0.30	0.47	0.58	0.67	0.75	0.82	0.89	0.95	1.01	1.07
	150	0.27	0.51	0.65	0.75	0.84	0.91	0.98	1.05	1.11	1.17
	200		0.53	0.71	0.83	0.92	1.00	1.07	1.14	1.21	1.27
	250			0.75	0.89	1.00	1.08	1.16	1.23	1.30	1.36
	300			0.78	0.95	1.06	1.16	1.24	1.32	1.39	1.45
Dairy goats[a]											
7	0	0.45	0.61	0.75	0.89	1.02	1.15	1.27	1.39	1.50	1.61
	50	0.50	0.69	0.85	0.99	1.13	1.25	1.38	1.49	1.61	1.72
	100		0.75	0.94	1.09	1.23	1.36	1.48	1.60	1.71	1.82
	150			1.00	1.17	1.32	1.45	1.58	1.70	1.81	1.92
9	0	0.37	0.50	0.62	0.73	0.84	0.95	1.05	1.14	1.24	1.33
	50	0.42	0.58	0.72	0.84	0.95	1.05	1.15	1.25	1.34	1.43
	100	0.43	0.65	0.80	0.93	1.05	1.15	1.25	1.35	1.45	1.54
	150	0.40	0.69	0.87	1.01	1.14	1.25	1.35	1.45	1.55	1.64
	200		0.71	0.93	1.09	1.22	1.34	1.44	1.55	1.64	1.73
	250			0.97	1.15	1.30	1.42	1.53	1.64	1.73	1.83
	300			1.00	1.21	1.36	1.50	1.61	1.72	1.82	1.92
11	0	0.32	0.43	0.53	0.63	0.73	0.82	0.90	0.99	1.07	1.15
	50	0.37	0.51	0.63	0.74	0.83	0.92	1.01	1.09	1.17	1.25
	100	0.38	0.58	0.72	0.83	0.93	1.02	1.11	1.20	1.28	1.36
	150	0.35	0.62	0.79	0.91	1.02	1.12	1.21	1.29	1.38	1.46
	200		0.64	0.84	0.99	1.10	1.21	1.30	1.39	1.47	1.55
	250			0.89	1.05	1.18	1.29	1.39	1.48	1.56	1.65
	300			0.92	1.10	1.25	1.37	1.47	1.57	1.65	1.74
13	0	0.28	0.38	0.48	0.56	0.65	0.73	0.80	0.88	0.95	1.02
	50	0.33	0.47	0.57	0.67	0.75	0.83	0.91	0.99	1.06	1.13
	100	0.34	0.53	0.66	0.76	0.85	0.93	1.01	1.09	1.16	1.23
	150	0.31	0.57	0.73	0.84	0.94	1.03	1.11	1.19	1.26	1.33

Table 13 (*Continued*)

MEC (MJ/kg)	ADG (g/day)	BW (kg)									
		10	15	20	25	30	35	40	45	50	55
	200		0.59	0.78	0.92	1.02	1.17	1.20	1.28	1.36	1.43
	250			0.83	0.98	1.10	1.20	1.29	1.37	1.45	1.52
	300			0.86	1.03	1.17	1.28	1.37	1.46	1.54	1.61
Indigenous goats[a]											
7	0	0.38	0.51	0.63	0.75	0.86	0.97	1.07	1.17	1.27	1.36
	50	0.41	0.58	0.72	0.84	0.96	1.06	1.17	1.26	1.36	1.45
	100		0.64	0.79	0.93	1.04	1.15	1.26	1.36	1.45	1.55
	150			0.85	1.00	1.12	1.24	1.34	1.45	1.54	1.64
9	0	0.31	0.42	0.52	0.62	0.71	0.80	0.88	0.96	1.04	1.12
	50	0.35	0.49	0.61	0.71	0.80	0.89	0.98	1.06	1.14	1.21
	100	0.35	0.55	0.68	0.79	0.89	0.98	1.07	1.15	1.23	1.31
	150	0.31	0.58	0.74	0.87	0.97	1.07	1.15	1.24	1.32	1.40
	200		0.59	0.79	0.93	1.04	1.14	1.24	1.32	1.40	1.48
	250			0.82	0.98	1.11	1.22	1.31	1.40	1.49	1.57
11	0	0.27	0.36	0.45	0.53	0.61	0.69	0.76	0.83	0.90	0.97
	50	0.30	0.44	0.54	0.63	0.71	0.78	0.86	0.93	1.00	1.06
	100	0.30	0.49	0.61	0.71	0.79	0.87	0.95	1.02	1.09	1.15
	150	0.26	0.52	0.67	0.78	0.87	0.96	1.03	1.11	1.18	1.24
	200		0.53	0.72	0.84	0.95	1.03	1.12	1.19	1.26	1.33
	250			0.75	0.90	1.01	1.11	1.19	1.27	1.34	1.41
13	0	0.24	0.32	0.40	0.47	0.54	0.61	0.68	0.74	0.80	0.86
	50	0.27	0.40	0.49	0.57	0.64	0.71	0.77	0.84	0.90	0.96
	100	0.27	0.45	0.56	0.65	0.73	0.80	0.86	0.93	0.99	1.05
	150	0.23	0.48	0.62	0.72	0.81	0.88	0.95	1.02	1.08	1.14
	200		0.49	0.67	0.78	0.88	0.96	1.03	1.10	1.16	1.22
	250			0.70	0.84	0.94	1.03	1.11	1.18	1.24	1.31

The ratio of ADG:BW was used to adjust for variation in DM intake related to variable energy concentration in mobilized or accreted tissue, and adjustments based on ratios of ADG to $BW^{0.75}$ (MBW) and MBW^2 were in regards to effect on the ME requirement for maintenance of previous nutritional plane. Therefore, knowledge of true ME requirements for maintenance and gain would be necessary to project these ADG from the listed DM intake estimates. MEC = dietary ME concentration. Based on estimates of Luo et al. (2004b).

[a] Meat ≥ 50% Boer; dairy = Saanen, Alpine, Damascus, Norwegian, Swedish landrace and dairy crossbreed; indigenous = neither meat nor dairy, not including Angora.

is hilly and walking distances are great. Furthermore, CSIRO (1990) presented a prediction equation with independent variables of DM digestibility, terrain score, availability of green or total forage and BW. However, NRC (2001) noted that because this equation has not been thoroughly evaluated and seems to yield relatively high activity energy costs, at least with moderate to high quality forage, an alternative approach should be considered. In this regard, NRC (2001) proposed an untested summative method for dairy cattle considering energy expended in three grazing functions, i.e., distance walked: 1.9 kJ/kg BW × km (ARC, 1980); eating: 12.6 kJ/kg BW; and topography or vertical ascent: 126 kJ/kg vertical distance. Similarly, Rochinotti (1998) developed an unvalidated system to predict ME_a for dairy cows considering grazing and walking distance, paddock size, vertical ascent, grazing time and pasture conditions.

3.2.2. Recent estimates

Estimates of ME_a for goats vary tremendously, ranging from 0 to 1 times the requirement of ME_m for confined goats in pens or stalls (Lachica and Aguilera, 2003). Lachica et al. (1999) found that energy expended by goats in locomotion was 47 and 32% of an assumed ME_m of 401 kJ/kg $BW^{0.75}$ with confined conditions in summer and autumn in a semi-intensive production system in a rugged Mediterranean mountain environment, with distance traveled ranging from 8.1 to 12.8 km. Conversely, in another semi-arid

Table 14
Estimates of voluntary DM intake (kg/day) by mature goats in a pen or stall environment

BW (kg)	ADG (g/day)	7 MJ/kg of ME				9 MJ/kg of ME				11 MJ/kg of ME				13 MJ/kg of ME			
		6% CP	9% CP	12% CP	15% CP	6% CP	9% CP	12% CP	15% CP	6% CP	9% CP	12% CP	15% CP	6% CP	9% CP	12% CP	15% CP
20	0	0.50	0.57	0.63	0.69	0.41	0.48	0.54	0.61	0.36	0.42	0.49	0.55	0.32	0.38	0.45	0.51
	20	0.52	0.58	0.65	0.71	0.43	0.50	0.56	0.63	0.38	0.44	0.51	0.57	0.34	0.40	0.47	0.53
	40					0.45	0.52	0.58	0.64	0.40	0.46	0.52	0.59	0.36	0.42	0.49	0.55
30	0	0.68	0.74	0.81	0.87	0.56	0.62	0.69	0.75	0.48	0.55	0.61	0.68	0.43	0.50	0.56	0.62
	20	0.74	0.80	0.87	0.93	0.62	0.68	0.75	0.81	0.54	0.61	0.67	0.74	0.49	0.56	0.62	0.68
	40	0.80	0.86	0.93	0.99	0.68	0.74	0.81	0.87	0.60	0.67	0.73	0.80	0.55	0.62	0.68	0.74
40	0	0.84	0.90	0.97	1.03	0.69	0.76	0.82	0.89	0.60	0.66	0.73	0.79	0.54	0.60	0.66	0.73
	20	0.91	0.98	1.04	1.11	0.77	0.83	0.90	0.96	0.67	0.74	0.80	0.87	0.61	0.67	0.74	0.80
	40	0.99	1.05	1.12	1.18	0.84	0.91	0.97	1.03	0.75	0.81	0.88	0.94	0.68	0.75	0.81	0.88
50	0	0.99	1.06	1.12	1.19	0.82	0.88	0.95	1.01	0.71	0.77	0.84	0.90	0.63	0.70	0.76	0.82
	20	1.07	1.14	1.20	1.27	0.90	0.96	1.03	1.09	0.79	0.85	0.92	0.98	0.71	0.78	0.84	0.90
	40	1.15	1.22	1.28	1.34	0.98	1.04	1.11	1.17	0.87	0.93	1.00	1.06	0.79	0.86	0.92	0.98
60	0	1.14	1.20	1.27	1.33	0.94	1.00	1.07	1.13	0.81	0.88	0.94	1.00	0.72	0.79	0.85	0.92
	20	1.22	1.28	1.35	1.41	1.02	1.08	1.15	1.21	0.89	0.96	1.02	1.09	0.81	0.87	0.93	1.00
	40	1.30	1.37	1.43	1.49	1.10	1.17	1.23	1.29	0.97	1.04	1.10	1.17	0.89	0.95	1.02	1.08
70	0	1.28	1.34	1.40	1.47	1.05	1.12	1.18	1.25	0.91	0.97	1.04	1.10	0.81	0.88	0.94	1.00
	20	1.36	1.42	1.49	1.55	1.14	1.20	1.26	1.33	0.99	1.06	1.12	1.19	0.89	0.96	1.02	1.09
	40	1.44	1.51	1.57	1.63	1.22	1.28	1.35	1.41	1.07	1.14	1.20	1.27	0.98	1.04	1.10	1.17
80	0	1.41	1.47	1.54	1.60	1.16	1.23	1.29	1.36	1.01	1.07	1.13	1.20	0.90	0.96	1.03	1.09
	20	1.49	1.56	1.62	1.69	1.25	1.31	1.37	1.44	1.09	1.15	1.22	1.28	0.98	1.04	1.11	1.17
	40	1.57	1.64	1.70	1.77	1.33	1.39	1.46	1.52	1.17	1.23	1.30	1.36	1.06	1.12	1.19	1.25

Because of the constant ADG used to derive the initial prediction of DM intake, with subsequent adjustment for dietary CP concentration, diets with low and high CP concentrations (e.g., 6–9 and 12–15%, respectively) should be accompanied by ADG slightly lower and greater, respectively, than listed. Likewise, the ratio of ADG:BW was used to adjust for variation in DM intake related to variable energy concentration in mobilized or accreted tissue, and adjustment by the ratio of ADG:BW$^{0.75}$ was in regards to effect on the ME requirement for maintenance of previous nutritional plane. Therefore, knowledge of true ME requirements for maintenance and gain would be necessary to project these ADG from the listed DM intake estimates. Based on estimates of Luo et al. (2004b).

Table 15
Estimates of metabolizable energy and protein (ME and MP, respectively) requirements of goats for pregnancy

Birth weight (kg)	Day	ME (MJ/day)			MP (g/day)		
		One kid[a]	Two kids[b]	Three kids[b]	One kid[a]	Two kids[b]	Three kids[b]
2	91–100[c]	*0.13*	0.26	0.41	*4.1*	5.8	8.8
	101–110	*0.69*	1.27	1.73	*9.8*	17.1	23.4
	111–120	*1.21*	2.07	2.84	*14.6*	25.6	35.1
	121–130	*1.66*	2.81	3.76	*19.5*	34.3	45.9
	131–140	*2.09*	3.43	4.58	*24.2*	41.8	55.7
	141–150	*2.46*	3.80	5.08	*27.6*	45.9	61.3
3	91–100	0.19	0.38	0.62	6.3	8.5	13.2
	101–110	1.03	1.90	2.60	14.8	25.6	35.1
	111–120	1.81	3.11	4.26	22.1	38.4	52.6
	121–130	2.50	4.22	5.63	29.3	51.6	68.7
	131–140	3.13	5.14	6.87	36.2	62.6	83.5
	141–150	3.68	5.70	7.62	41.4	68.7	91.8
4	91–100	0.24	0.50	*0.84*	8.2	11.6	*17.6*
	101–110	1.37	2.53	*3.47*	19.7	34.2	*46.9*
	111–120	2.41	4.14	*5.68*	29.3	51.2	*69.9*
	121–130	3.33	5.63	*7.51*	39.2	68.7	*91.8*
	131–140	4.17	6.86	*9.16*	48.3	83.5	*111.5*
	141–150	4.91	7.61	*10.15*	55.2	91.8	*122.5*
5	91–100	0.32	*0.63*	*1.05*	10.2	*14.3*	*21.8*
	101–110	1.72	*3.16*	*4.34*	24.6	*42.7*	*58.5*
	111–120	3.01	*5.18*	*7.10*	36.6	*64.0*	*87.8*
	121–130	4.16	*7.03*	*9.39*	49.0	*85.9*	*114.6*
	131–140	5.22	*8.57*	*11.44*	60.3	*104.4*	*139.3*
	141–150	6.14	*9.51*	*12.69*	68.9	*114.6*	*153.0*

Based on sheep fetal growth curves (Koong et al., 1975), sheep body composition data (Rattray et al., 1974) and efficiencies of use for pregnancy of 0.133 (ARC, 1980) and 0.33 (NRC, 2001) for ME and MP, respectively. CP requirements can be estimated from MP requirements and dietary concentration of undegraded intake protein (UIP; dietary CP that reaches the small intestine as intact protein). For example, with diets containing 20, 40 and 60% UIP as a percentage of consumed CP, MP requirements can divided by efficiencies of conversion of CP to MP of 0.672, 0.704 and 0.736, respectively (NRC, 2000).

[a] Values in italics may not be employed since greater birth weights of single kids are likely.

[b] Based on 37 and 33.5% greater ME and MP requirements, respectively, for does with three than two kids, respectively (AFRC, 1998). Values in italics may not be employed since lower birth weights of twins and triplets are likely.

[c] Requirements for days 91–100 (average of 95 days) were determined from regressions (linear and quadratic effects) of ME and MP requirements for later periods against average days of gestation.

Mediterranean zone in the same region, energy expenditure due to locomotion was only 14 and 9% above an assumed ME_m of 443 kJ/kg $BW^{0.75}$ (Lachica et al., 1997b). In a recent unpublished experiment cited by Lachica and Aguilera (2003) and conducted at Langston University, ME_a of yearling crossbred Boer goats grazing grass-based pasture in summer was 43% of ME_m of restricted movement goats. In another unpublished experiment cited by Lachica and Aguilera (2003) and conducted at Langston University, ME_a was 50 and 24% of an assumed restricted movement ME_m of 443 kJ/kg $BW^{0.75}$ for yearling crossbred goats grazing grass-based pastures with low and high available forage mass, respectively, due to different stocking rates.

3.2.3. Factors contributing to ME_a

Although some empirical methods to predict ME_a rely only on energy for movement (e.g., AFRC, 1998), or movement and eating as a function of BW (e.g., NRC, 2001), Osuji (1974) discussed other processes that could account for much of ME_a. Greatest attention was given to happenings in splanchnic tissues (primarily the digestive tract plus liver) since they can account for well over half of whole body heat production in housed ruminants (Ferrell, 1988). Blood flow to and energy use by splanchnic tissues are much greater during eating than at other times (Seal and Reynolds, 1993). Rémond et al. (2002) noted highest ruminal blood flow during meal consumption by penned sheep, without an effect of a ruminal starch dose 3 h after the meal. Likewise, fistula feeding has induced no or little change in energy expenditure (EE) relative to that while eating (Osuji et al., 1975; Lachica et al., 1997a). Hence, it seems that physiological conditions in the whole body associated with the act of eating, not necessarily simply prehension, prehension mastication and (or) saliva flow during ingestion, elicit increased EE, as also concluded by Lachica and Aguilera (2003). Furthermore, heat production by splanchnic tissues may not vary only with eating time, but rather can be influenced by the nature of the diet. Energy use by the digestive tract plus liver increases with increasing diet quality and nutrient absorption (Johnson et al., 1990). However, in confined sheep consuming diets ad libitum, energy use by these tissues relative to energy absorption increases with decreasing diet quality (Goetsch, 1998), and similar findings have been noted with limit-fed cattle (Huntington et al., 1988; Reynolds et al., 1991). Although effects of diet quality on time spent eating could account for some of this effect, there are other factors likely involved as well, such as the array of endproducts of digestion and physical characteristics of diets (Goetsch, 1998).

The importance of walking time, distance traveled and terrain to energy used by goats in activity have been studied by Lachica et al. (1997b,c, 1999) and recently reviewed by Lachica and Aguilera (2003). Although it is possible that energy costs per unit time spent grazing and walking are not constant, it is likely that such differences vary with factors such as diet quality, and goat producers might find it difficult to assess separate grazing and walking times.

A somewhat greater amount of research regarding effects on activity energy costs of factors such as grazing and walking times, distance traveled and terrain have been conducted with other ruminant species compared with goats. In regards to grazing time, Allden and Wittaker (1970) noted an increase in grazing time from 6 h and 40 min to 12 h and 30 min with a decrease in herbage mass from 4000 to 500 kg DM/ha. In addition, the physical structure of herbage influenced grazing time via an effect on rate of DM intake, which generally increased with increasing plant height. Another factor influencing grazing time is supplementation with higher quality feedstuffs than forage being grazed, causing a decrease as level of supplementation increases (Sarker and Holmes, 1974; Combellas et al., 1979). Forage quality and availability not only influence grazing time, but also affect the proportion of total grazing and walking time spent in each activity. For example, distance traveled is less with a high versus low density of palatable plants (Bailey et al., 1996) and with low versus high stocking rate (Quinn and Harvey, 1970).

In a literature review by Rochinotti (1998), distance traveled by cattle ranged from 0.9 to 12.6 km/day, although it was stated that highest values were not necessarily applicable to production systems in dry regions entailing periodic long trips to water. In accordance, location of water and mineral sources influence distance traveled (Heady, 1975; Squires and Wilson, 1971; Pinchak et al., 1991). Paddock size can impact distance traveled by cattle (Shepperd, 1921; Hart et al., 1993), and distance traveled also has varied among cattle genotypes (Herbel and Nelson, 1966; Sneva, 1970).

3.2.4. Future ME_a prediction system for development

Although in the last few years there has been some research conducted concerning ME use in grazing activities, at present there is not in place a prediction system for easy use by goat producers. However, some of the major factors affecting ME_a have been identified, even though accurate estimates of effects and interactions have not yet been well delineated. Thus, a system is described that might be developed through further experimentation to estimate ME_a based on variables that could be readily estimated in the field, with an approach similar to that of George (1984) and Rochinotti (1998). ME_a (multiple of ME_m, inclusive of the activity energy cost of pen or stall conditions) of 0.05, 0.10, 0.15, 0.20, 0.25, 0.30, 0.35, 0.40, 0.45, and 0.50 was assumed for grazing plus walking times of 4, 5, 6, 7, 8, 9, 10, 11, 12 and 13 h, respectively. This factor was then adjusted for diet quality, distance traveled and terrain score. Diet quality is total digestible nutrient concentration or apparent organic matter digestibility; for diet qualities of 40, 45, 50, 55, 60, 65, 70 and 75%, multiplication factors are 1.20, 1.15, 1.10, 1.05, 1.00, 0.95, 0.90 and 0.85, respectively. For distance traveled

Table 16
Estimates of metabolizable energy (ME) requirements (multiple of the ME requirement for maintenance) of goats for grazing activity (ME_a) based on grazing and walking time (GWT), diet quality (DQ), distance traveled (DT) and terrain (TR)

Diet quality	Distance traveled	Terrain	Grazing + walking time (h)		
			4[a]	8	12[b]
45	3	1	*0.047*	0.233	0.419
		3	*0.052*	0.259	0.466
		5	*0.062*	0.311	0.559
	6	1	*0.054*	0.272	0.489
		3	*0.060*	0.302	0.543
		5	*0.072*	0.362	0.652
	9	1	*0.062*	0.311	0.559
		3	*0.069*	0.345	0.621
		5	*0.083*	0.414	0.745
	12	1	*0.070*	0.349	0.629
		3	*0.078*	0.388	0.699
		5	*0.093*	0.466	0.838
60	3	1	0.041	0.203	0.345
		3	0.045	0.225	0.405
		5	0.054	0.270	0.486
	6	1	0.047	0.236	0.425
		3	0.053	0.263	0.473
		5	0.063	0.315	0.567
	9	1	0.054	0.270	0.486
		3	0.060	0.300	0.540
		5	0.072	0.360	0.648
	12	1	0.061	0.304	0.547
		3	0.068	0.338	0.608
		5	0.081	0.405	0.729
75	3	1	0.034	0.172	*0.310*
		3	0.038	0.191	*0.344*
		5	0.046	0.230	*0.413*
	6	1	0.040	0.201	*0.361*
		3	0.045	0.223	*0.402*
		5	0.054	0.268	*0.482*
	9	1	0.046	0.230	*0.413*
		3	0.051	0.255	*0.459*
		5	0.061	0.306	*0.551*
	12	1	0.052	0.258	*0.465*
		3	0.057	0.287	*0.516*
		5	0.069	0.344	*0.620*

ME_a (multiple of ME_m for goats in pen or stall conditions) of 0.05, 0.10, 0.15, 0.20, 0.25, 0.30, 0.35, 0.40, 0.45 or 0.50 was assumed for GWT of 4, 5, 6, 7, 8, 9, 10, 11, 12 or 13 h, respectively. DQ is TDN concentration or apparent OM digestibility; for DQ of 40, 45, 50, 55, 60, 65, 70 or 75%, 1.20, 1.15, 1.10, 1.05, 1.00, 0.95, 0.90 and 0.85, respectively, was multiplied by ME_a based on GWT. For distance traveled (DT) of 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14 or 15 km, 0.85, 0.90, 0.95, 1.00, 1.05, 1.10, 1.15, 1.20, 1.25, 1.30, 1.35, 1.40, 1.45 or 1.50, respectively, was multiplied by ME_a based on GWT and DQ. TR = 1–5, with 1 being nearly level pasture and 5 being range conditions with very steep slopes and extremely rugged topography; for TR of 1, 2, 3, 4 or 5, 0.90, 0.95, 1.00, 1.10 or 1.20, respectively, were multiplied by ME_a based on GWT, DQ and DT.

[a] Values in italics may not be employed since longer GWT are likely.

[b] Values in italics may not be employed since shorter GWT are likely.

of 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14 and 15 km, multiplication factors are 0.85, 0.90, 0.95, 1.00, 1.05, 1.10, 1.15, 1.20, 1.25, 1.30, 1.35, 1.40, 1.45 and 1.50, respectively. The terrain score is 1–5, with 1 being nearly level pasture and 5 being range conditions with very steep slopes and extremely rugged topography; for terrain scores of 1, 2, 3, 4 and 5, multiplication factors are 0.90, 0.95, 1.00, 1.10 and 1.20, respectively. Although there may be confounding among these factors, it was felt desirable to include each to adequately account for their influences on energy expenditure. For example, diet quality would affect grazing time but also can influence heat production relative to ME intake by splanchnic tissues. Likewise, distance traveled and a consideration of terrain adjust energy expenditure predicted from grazing and walking time. Values are presented in Table 16 for various scenarios. There are not presently published data available to assess accuracy of this simple system.

3.3. Environment

3.3.1. Acclimatization

Goats are raised in many different environments throughout the world. Although there has been less research of environmental effects on nutritional needs of goats compared with cattle or sheep, the same general principles should apply, such as those discussed by NRC (2000).

To account for acclimatization, NRC (2000) adjusted the net energy for maintenance requirement (NE_m) for deviation in temperature from 20 °C, the mid-point of the thermo-neutral zone, with this equation:

$$NE_m = (0.0029 \times (20 - T_p)) \times 0.322\,\mathrm{MJ/kg\,BW^{0.75}},$$

with T_p being average ambient (air) temperature (°C) in the previous 30 days. This reflects a 2.9 kJ/kg $BW^{0.75}$ change for each degree that previous ambient temperature differed from 20 °C. A similar adjustment could be applied with goats, but perhaps with consideration of using a mid-point thermo-neutral zone temperature specific for the goat genotype of interest rather than 20 °C in all cases. Because requirement estimates developed in this project were generally for ME_m rather than NE_m, the calculated difference in NE_m can be divided by an assumed efficiency of ME utilization for maintenance such as 0.69–0.70 (Luo et al., 2004e; Nsahlai et al., 2004a), with use of the result to adjust a listed ME_m requirement. Effects of acclimatization may relate to indications that desert goats have lower maintenance energy needs compared with goats in other environments (Silanikove, 2000).

3.3.2. Cold stress

Cold and heat stress can impact energy needs of livestock. Even though some goats are well adapted to cold conditions, such as ones with high cashmere production, many in the US are not, being more suited for hot, dry conditions. One reason for this is the generally lesser amount of subcutaneous fat in goats than in cattle or sheep. Hence, use of equations of NRC (2000) to estimate effects of cold stress on energy needs would require careful selection of assumptions. Below is a brief description of the NRC (2000) approach for beef cattle, along with some suggestions for use with goats.

Total insulation (IN) is the sum of tissue (TI) and external insulation (EI). TI (°C/MJ/m^3/day) is primarily due to subcutaneous fat and skin thicknesses, with values of 0.60, 1.55, 1.31–1.91 and 1.43–2.87 for newborn calf, 1-month-old calf, yearling cattle and adult cattle, respectively. For high cashmere or mohair fiber producing goats and ones in high body condition, a value in the range of yearling or adult cattle seems reasonable. But for others in moderate to low body condition and not producing high amounts of fiber, or after shearing, values in the newborn to 1-month-old calf range could be most appropriate.

EI was estimated by this equation:

$$EI = (1.759 - 0.0707 \times \mathrm{WIND} + 0.6095 \times \mathrm{HAIR}) \times \mathrm{MUD} \times \mathrm{HIDE},$$

with EI as °C/MJ/m^2, WIND = km/h, HAIR (effective) as cm and MUD and HIDE being adjustments for thicknesses. An important consideration for goats is wetness of the hair coat that decreases the boundary layer of air to decrease EI. Thus, it is suggested that an appropriate adjustment be used. In addition to influence on EI, with rainfall in cold conditions goats seek shelter when available, with an effect on feed intake.

The low critical temperature (LCT) was determined as

$$\mathrm{LCT} = 39 - \mathrm{IN} \times \left(\frac{\mathrm{HE}}{\mathrm{SA}} - H_\mathrm{e}\right),$$

with HE is the heat energy, SA the surface area (SA, $\mathrm{m}^2 = 0.09\,\mathrm{kg}\,\mathrm{BW}^{0.67}$) and H_e the minimal total evaporative heat loss ($H_\mathrm{e} = \mathrm{HE}/\mathrm{SA} \times 0.15$). Then, effective ambient temperature (EAT) was estimated by consideration of skin exposure to the environment, with an increase in bright exposure to sunlight of 3–5 °C and loss of up to 5 °C on cold clear nights with temperature of −10 to 10 °C. The increase in ME need because of cold stress ($\mathrm{ME_c}$) was determined as

$$\mathrm{ME_c} = \mathrm{SA} \times \frac{\mathrm{LCT} - \mathrm{EAT}}{\mathrm{IN}},$$

with $\mathrm{ME_c}$ as MJ/day, SA as m^2 and LCT and EAT as °C.

Another consideration for cold stress is a typical decrease in digestibility because of an increased rate of digesta passage (NRC, 2001). Also, the protein requirement as a percentage of DMI may be lower with cold stress when DMI is increased.

3.3.3. Heat stress

As noted earlier, many goats are well adapted to high temperature, but heat stress can still occur. Heat stress increases energy use primarily through increases in tissue metabolism and respiration and heart rates. This area has not received much research attention with goats and, in fact, NRC (2000) concluded that there was not an adequately established system available to describe effects of heat stress on energy needs of beef cattle. It was, however, suggested that the type and intensity of panting be used to adjust the maintenance requirement, with an increase of 7% for rapid shallow breathing and of 11–25% for deep, open-mouth panting.

3.4. Parity

There were inadequate data with goats available to provide clear recommendations for deviation in nutritional requirements between primiparous and multiparous females. It is doubtful that requirements for does kidding at 2 years of age differ substantially from multiparous does 2 years of age or older. But, for lactating yearling does, it is suggested that the assumptions used by Nsahlai et al. (2004a), 23.9 MJ/kg of accreted tissue (AFRC, 1993, 1998) and an efficiency of use of dietary ME for tissue gain of 0.75 (NRC, 1989), be used. Likewise, it is suggested that assumptions of Nsahlai et al. (2004b), 14.3% protein in accreted tissue (AFRC, 1993, 1998) and an efficiency of MP used for gain of 0.59 (AFRC, 1993, 1998), be employed to estimate the MP requirement for gain.

3.5. Lactation and stage of lactation

Nsahlai et al. (2004a) evaluated the assumption of NRC (2001) that $\mathrm{ME_m}$ is 20% greater for lactating versus non-lactating cattle; resultant regression equations exhibited significant bias when used to predict values with the evaluation data set. Also, as discussed by Nsahlai et al. (2004a), it is likely that $\mathrm{ME_m}$ is not constant throughout lactation, although insufficient data with goats were available to provide a justifiable recommendation for change.

3.6. Season

There is increasing evidence that for cattle and sheep, season of the year affects $\mathrm{ME_m}$ and feed intake apart from the influence of temperature. However, inadequate data were available to suggest seasonal adjustments for nutrient requirement expressions for goats.

3.7. Gender

NRC (2000) concluded that relative to $\mathrm{BW}^{0.75}$ and rate of gain, ME and MP requirements for beef cattle were similar between heifers and steers or male castrates, but suggested a 15% greater $\mathrm{ME_m}$ for intact males. A similar difference between bucks versus other goat genders seems reasonable. However, in many studies used by Luo et al. (2004e), gender was not reported, which precluded assessment of its potential effect. Hence, it is suggested that $\mathrm{ME_m}$ requirements of Luo et al. (2004e) for growing goats be decreased by 7.5% for females and male castrates and increased by 7.5% for intact males. Mature goat observations of Luo et al. (2004e) were primarily with females and male castrates; hence, $\mathrm{ME_m}$ for intact males can be calculated as 115% of estimate of Luo et al. (2004e). ME requirements listed in Tables 2–4 include these adjustments.

3.8. Age and stage of maturity

Some but not all findings with other ruminant species suggest decreasing fasting heat production and ME_m with increasing age. However, based on available research at that time, NRC (1996) did not adjust ME_m of beef cattle for age. There were no data available for goats regarding potential effects of age. Also, Luo et al. (2004e) reported a ME_m of mature goats (462 kJ/kg $BW^{0.75}$), slightly lower than for growing indigenous and mature goats (489 kJ/kg $BW^{0.75}$) and suckling goats (485 kJ/kg $BW^{0.75}$). Thus, no additional adjustment for age is presently recommended.

3.9. Biotype and genotype

As noted in the preceding reports, because of the large number of genotypes in the database and in some cases fairly general descriptions, it was not possible to investigate potential genotype differences. Rather, goats were categorized into different biotypes regarding previous degree of selection for specific production characteristics that conceivably could impact nutritional needs. Then, for simplicity biotypes were grouped whenever intercepts and slopes of regression equations were not different. Future research may identify differences among genotypes within biotypes.

With the data set used to investigate ME_m of mature goats (Luo et al., 2004e), there was not a significant difference in regression equations between indigenous and dairy goats, although the number of observations was not great. Therefore, assuming that relative differences between biotypes in ME_m of growing goats was maintained to maturity (NRC, 2000), the ME_m requirement was assumed to be 501.3 and 422.7 kJ/kg $BW^{0.75}$ for mature dairy and indigenous goats, respectively, in accordance with the assumption of NRC (2000) that relative differences among beef cattle genotypes in ME_m are consistent across ages and stages of maturity. Nsahlai et al. (2004a) found this method to be as accurate as that based on AFRC (1993, 1998) assumptions.

3.10. Plane of nutrition

After a limited nutritional plane, growth by other ruminant species may be more rapid or efficient than expected based on nutrient intake, because of increased feed intake and (or) efficiency of metabolism (NRC, 2000). NRC (2000) suggested that compensatory growth may occur for 2–3 months and that ME_m could be decreased by 20% during this time. Compensatory growth also can occur in goats (Joemat et al., 2004; Urge et al., 2004; Wuliji et al., 2003); however, these recent studies suggest possible differences among realimentation diets differing in quality and among goat genotypes. Nonetheless, it is suggested that ME_m be decreased for up to 3 months following a low plane of nutrition by 1–20%, depending on the severity of restriction (e.g., level and length), with the reduction decreasing as the period of realimentation advances. In this regard, the ratio of ADG:$BW^{0.75}$ (ADGMBW) was used for mature goats and ADGMBW and $ADGMBW^2$ were used for growing goats to derive predictions of feed intake to address effects of previous nutritional plane.

3.11. Diet quality and level of intake

Diet quality can influence efficiency of metabolism (ARC, 1980; NRC, 1984). Inadequate data were available to estimate NE requirements for non-lactating goats. Nonetheless, ME does not account for differences among diets in efficiency of metabolism for maintenance and particularly gain. Therefore, accuracy of requirements or prediction of performance based on ME requirement estimates will decrease as the differences in dietary ME concentration from means increase. Thus, a possible method of adjusting estimates of intake of diets differing in ME concentration necessary to achieve desired levels of production was developed.

Mean dietary ME concentrations in the databases used were close to 10 MJ/kg or 2.4 Mcal/kg, which thus was used as a baseline for adjustment. The AFRC (1998) equations, $k_m = 0.503 + (0.019 \times \text{ME, MJ/kg})$ and k_g (efficiency of ME use for whole body gain) $= 0.006 + (0.0423 \times \text{ME, MJ/kg})$, were used to predict values for diets listed by NRC (1984) in the table on p. 3 entitled “Efficiency of ME use for maintenance and gain” and also two diets lower in ME. Differences

Table 17
Factors to adjust level of intake for effects of dietary ME concentration on efficiency of ME utilization for maintenance and gain by non-lactating goats

Dietary ME (MJ/kg DM)	k_m[a]	k_g[b]	Intake adjustment factor[c]		
			1	2[d]	3[d]
6.694	0.630	0.289	1.101	*1.280*	*1.340*
7.530	0.646	0.325	1.074	1.187	*1.225*
8.368	0.662	0.360	1.048	1.110	1.131
9.205	0.678	0.395	1.024	1.046	1.053
10.042[e]	0.694	0.431	1.000	1.000	1.000
10.879	0.710	0.502	0.978	0.942	0.929
11.715	0.726	0.502	0.956	0.899	0.880
12.552	0.741	0.537	0.936	0.861	0.836
13.389	0.757	0.572	0.916	0.827	0.797

[a] Efficiency of ME utilization for maintenance; estimated from the equation: $0.503 + (0.019 \times \mathrm{ME, MJ/kg})$ (AFRC, 1998).
[b] Efficiency of ME utilization for gain: $0.006 + (0.0423 \times \mathrm{ME, MJ/kg})$ (AFRC, 1998).
[c] Intake adjustment factors can be multiplied by DM intake estimates derived from ME requirement estimates of Luo et al. (2004e) to supply needed ME for 1, 2 and 3 times ME_m to account for effects of dietary ME concentration on efficiency of ME utilization for maintenance and gain.
[d] Values in italics may not be employed since high intake of low quality diets is unlikely.
[e] 10.042 MJ/kg was the approximate average ME concentration in the database.

Table 18
Factors to adjust level of intake for effects of dietary ME concentration on efficiency of ME utilization for maintenance and lactation based on Method 2 of estimating the dietary ME requirement for lactation

Dietary ME (MJ/kg DM)	k_m[a]	Intake adjustment factor[b]		
		2	3[c]	4[c]
6.694	0.630	1.052	*1.035*	*1.027*
7.530	0.646	1.039	1.026	*1.020*
8.368	0.662	1.025	1.017	1.013
9.205	0.678	1.013	1.009	1.007
10.042[d]	0.694	1.000	1.000	1.000
10.879	0.710	0.988	0.992	0.994
11.715	0.726	0.976	0.983	0.987
12.552	0.741	0.964	0.975	0.981
13.389	0.757	0.953	0.967	0.975

[a] Efficiency of ME utilization for maintenance; estimated from the equation: $0.503 + (0.019 \times \mathrm{ME, MJ/kg})$ (AFRC, 1998).
[b] Intake adjustment factors can be multiplied by DM intake estimates derived from ME requirement estimates from Method 2 of Nsahlai et al. (2004a) to supply needed ME for two, three and four times ME_m to account for effects of dietary ME concentration on efficiency of ME utilization for maintenance and lactation (0.589).
[c] Values in italics may not be employed since high intake of low quality diets is unlikely.
[d] 10.042 MJ/kg was the approximate average ME concentration in the database.

in k_m for the diets of NRC (1984) higher and lower in ME than 10.042 MJ/kg (i.e., the approximate mean of diets of the database) were estimated, which are intake adjustment factors for a level of feed intake providing one times ME_m. Likewise, adjustment factors for levels of intake two and three times ME_m were determined. Similar procedures were employed for lactation based on efficiencies of Nsahlai et al. (2004a) and tissue gain and clean mohair fiber growth by Angora goats with findings of Luo et al. (2004d). Multiplication of DMI predicted to supply needed ME by intake adjustment factors presented in Tables 17–19 should yield DMI estimates that account for effects of dietary ME concentration on efficiency of metabolism, which

Table 19
Factors to adjust level of intake for effects of dietary ME concentration on efficiency of ME utilization for maintenance and tissue gain with different levels of intake and proportions of ME above maintenance used for mohair fiber growth by Angora goats

Dietary ME (MJ/kg)	k_m	k_{tg}	$1.5 \times ME_m$ (ME_{fg} (% ME_{tfg}))				$2.5 \times ME_m$ (ME_{fg} (% ME_{tfg}))				$3.5 \times ME_m$ (ME_{fg} (% ME_{tfg}))			
			55	70	85	100	55	70	85	100	55	70	85	100
6.694	0.63	0.29	1.14	1.12	1.10	1.09	1.20	1.16	1.11	1.05	1.23	1.18	1.11	1.03
8.368	0.66	0.36	1.06	1.06	1.05	1.04	1.09	1.07	1.05	1.03	1.10	1.08	1.05	1.02
10.042[a]	0.69	0.43	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
11.715	0.73	0.50	0.94	0.95	0.95	0.96	0.91	0.93	0.95	0.98	0.90	0.92	0.95	0.98
13.389	0.76	0.57	0.89	0.90	0.91	0.93	0.84	0.87	0.90	0.95	0.82	0.86	0.90	0.97

ME_m: ME requirement for maintenance; k_m: efficiency of ME utilization for maintenance ($0.503 + (0.019 \times \mathrm{ME, MJ/kg})$; AFRC, 1998); k_{tg}: efficiency of ME use for non-fiber or tissue gain ($0.006 + (0.0423 \times \mathrm{ME, MJ/kg})$; AFRC, 1998); ME_{fg}: ME used for clean fiber growth; ME_{tfg}: ME used for tissue gain and fiber growth. Efficiency of ME used for clean fiber growth was 0.15 (Luo et al., 2004d).
[a] 10.042 MJ/kg was the approximate average ME concentration in the database.

should be comparable to intake estimates derived from NE requirements and dietary concentrations but that do not consider composition of tissue gain.

4. Research needs for more accurate nutrient requirement expressions of the future

4.1. Introduction

In addition to usefulness of the derived estimates, this project and the subsequent reports have highlighted gaps in knowledge necessary for most accurate prediction of goat nutrient requirements.

4.2. Energy

4.2.1. Composition of BW change

ME_m requirements were determined by regressing ME intake against BW change or ADG. Some factors that might affect ME_m could not be considered. For example, in other ruminant species the energy content of accreted tissue increases with increasing BW or stage of maturity and ADG (NRC, 1984, 1996). However, there are few reports in the literature with slaughter of goats at more than one age (e.g., Ash and Norton, 1987; Alam et al., 1991). Equations of AFRC (1998) describing composition of live weight gain for growing goats considered BW but not ADG and were based on a relatively small amount of data. Furthermore, AFRC (1998) found inadequate data to predict composition of BW change for mature goats.

Knowledge of the composition of BW change is necessary to assess NE requirements, which more accurately describe energy needs and performance with consumption of diets differing in metabolizability. In this regard, with high internal fat deposition in goats relative to most beef cattle and sheep (Potchoiba et al., 1980; Khidir et al., 1998), equations for other ruminant species describing change in composition as BW and stage of maturity increase may not be easily adaptable to goats. In this regard, the ratio of ADG:BW was used to derive estimates of voluntary feed intake by growing and mature goats to address variable energy concentration in mobilized tissue, and regression coefficients suggested a decreased tissue energy concentration with increasing ADG.

Body composition is not frequently measured in part because of high costs and labor associated with harvest and the determination of chemical composition of the whole body or carcass and non-carcass components. Furthermore, such measures are terminal, necessitating assumptions of similar composition of other animals at later times in serial slaughter experiments. Therefore, there is need for simple, inexpensive and non-terminal means of assessing body composition of goats. A possible less expensive technique is carcass specific gravity. However, potential utility of this method could be limited because of high internal fat deposition in goats. Urea dilution or urea space is a technique of indirectly determining body composition that has been shown useful with beef cattle and sheep (Preston and Kock, 1973; Hammond et al., 1984; Rule et al., 1986; Bartle et al., 1987; Poland, 1991). However, it has not been widely applied with goats. Arta Putra et al. (1998) used urea space with Etawah crossbred goats, although the equations used were derived from beef cattle data or were taken from the literature. Hence, development of equations for use of urea space to predict body composition of goats would be beneficial though comparative slaughter is still required to elucidate site of tissue accretion.

4.2.2. Constant ME_m

A number of factors influence ME_m, among which are genotype or biotype, age and previous or current nutritional plane. Age was given attention by classification, but it is recognized that in other ruminant species change is continuous or incremental (Freetly et al., 1995, 2003). Thus, studies are needed to address the pattern of decline in maintenance energy needs of goats with advancing maturity.

Ruminants are frequently exposed to shifts in nutritional plane, resulting in periods of body energy stasis or decline followed by times when body energy increases, which at least in the early part of the realimentation phase occurs at a rate greater than predicted based on level of intake (i.e., compensatory growth). As noted earlier, one of the consequences of nutritional plane is a change in heat production per unit metabolic body size. Silanikove (2000) suggested that such effects may be greater for goats than for other ruminant species, although differences among biotypes or genotypes within a biotype, all adapted to a particular environment, have not been extensively investigated. Silanikove (2000) also indicated that differences among goat genotypes in potential magnitude of adaptation (i.e., change in fasting heat production) to fluctuating energy intake are appreciable. Thus, effects of nutrient restriction on energy use by goats is deserving of research attention, as well as nutrient use and increase in body energy stasis with realimentation.

4.2.3. Activity

Goats are active animals, implying that energy used in activity might be high relative to other ruminant species. Also, effects of the unique herbaging behaviors of goats on heat production have not yet received much attention. Techniques appropriate for estimating energy expenditure by goats when browsing, such as heart rate coupled with estimated heat production per beat that has been used in cattle and sheep (Yamamoto et al., 1979; Yamamoto and Ogura, 1985; Purwanto et al., 1990; Brosh et al., 1998a,b, 2001; Liang et al., 1998; Arieli et al., 2002; Barkai et al., 2002), should be evaluated and hopefully used with goats.

4.3. Protein

4.3.1. Ruminally undegraded protein

To develop expressions of MP requirements, a database for crude protein degradability properties of dietary ingredients was constructed (Luo et al., 2004c,d; Nsahlai et al., 2004b). Properties included soluble CP, insoluble protein potentially degradable or undegradable in the rumen and acid detergent insoluble protein, with non-protein CP and true protein components of soluble CP. These properties were derived from publications with other ruminant species. There are relatively few estimates in the literature of ruminal outflow of feed, microbial and endogenous protein for goats. The rate of degradation of insoluble protein also was determined from available literature sources with other ruminant species. Particulate outflow rate from the rumen was estimated with an AFRC (1993) equation for ruminants based on level of ME intake relative to ME_m, and fluid passage rate was assumed to be a function of particulate passage rate based on a study with cattle (Nsahlai et al., 1999). Microbial protein synthesis in the rumen was determined from ruminally fermented energy means for roughage and concentrate of AFRC (1993) and level of ME intake relative to ME_m. The NRC (1984) equation for scurf protein loss in beef cattle was assumed, and estimates of endogenous urinary and metabolic fecal CP from Luo et al. (2004a) and Moore et al. (2004), respectively, were employed.

Effects of ruminally fermented energy (RFE) on microbial protein synthesis might not greatly vary among ruminant species with diets providing adequate ruminally available nitrogen (Silanikove, 2000); however, for other conditions such as passage rates and scurf protein loss it would be preferable to use equations or estimates derived from studies with goats. For example, Silanikove (2000) cited studies in which ruminal digesta passage rates in goats were greater or lower than in other ruminant species, and suggested marked influence on passage rates in goats of the nature of the diet. As mentioned for ME_g, estimating MP required for gain by regressing MP intake against ADG assumes a constant protein concentration in accreted tissue within age or biotype class, again indicating the desirability of further study of the composition of tissue accretion in growing meat goats. Another consideration in need of attention, fairly specific to goats, is consumption of plants with anti-quality factors, such as condensed tannins, that may impact behavior of feedstuff constituents in the digestive tract, as well as maintenance protein and energy losses. Moreover, goats seem more efficient in nitrogen recycling (Domingue et al., 1992; Landau et al., 1996; AFRC, 1998) than cattle or sheep, which may explain why digestibility and performance typically are slightly greater for goats versus cattle or sheep with diets based on low-quality forage and low in CP content. Thus, research is needed to determine dietary CP levels and ratios of CP:RFE below which ruminal availability of nitrogenous compounds, rather than RFE, limits microbial growth.

4.3.2. Maintenance losses

The scurf CP loss for goats might not be accurately described by the beef cattle equation of NRC (1984) used and could differ among goat genotypes. Another area deserving of future research attention is efficiency of use of MP for maintenance losses. For example, NRC (2000) assumes an efficiency of 0.65, whereas 1.00 is used by AFRC (1993, 1998). But, NRC (2000) corrected metabolic fecal CP via a number of assumptions for bacterial cell debris, which may partially compensate for a lower efficiency than used by AFRC (1993, 1998).

As noted previously, the recommended nutrient requirement expressions are for animals not incurring appreciable levels of parasitism. Some types of internal parasites increase loss of endogenous protein along with damage to tissue of the digestive tract (Poppi et al., 1986; Brown et al., 1991). In addition to increased dietary protein requirements with moderate to high degrees of internal parasitism, maintenance energy requirements would be elevated as well. Research is necessary to determine at what levels of different types of parasitism maintenance nutrient requirements should be increased, along with change in requirements as level of parasitism increases beyond this presumed threshold.

5. Summary and conclusions

A database of treatment mean observations from the literature was constructed and used to develop expressions describing energy and protein requirements of goats. Application of these estimates, in conjunction with appropriate adjustments for particular conditions, may lead to feeding of diets that will yield desired levels of performance by goats. Future research is required to develop more accurate nutrient requirement expressions unique to goats.

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