



## Nitrogen balance and blood metabolites of alpaca (*Lama pacos*) fed three forages of different protein content

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### Abstract

Sixteen intact male alpaca consisting of four age groups (AG1,  $16 \pm 4.4$  months,  $44.3 \pm 9.2$  kg; AG2,  $25 \pm 1.8$  months,  $51.7 \pm 2.3$  kg; AG3,  $35 \pm 1.1$  months,  $64.7 \pm 15.6$  kg; and AG4,  $60 \pm 12.0$  months,  $67.0 \pm 8.2$  kg) were housed in metabolism crates ( $20^\circ\text{C}$  with 12:12 h on:off light cycle). Three forages, straw (ST), grass hay (GH) and alfalfa (ALF) were fed to each alpaca in random order. The forages were fed at 12 h intervals with water provided ad libitum. Treatment periods were 14 days, with blood samples collected over a 24 h period on day 14 to determine temporal patterns of plasma metabolite and electrolytes. Dry matter intake was lower ( $P < 0.002$ ) for ST at 212 g/day, while GH and ALF were 678 and 715 g/day, respectively. Nitrogen intake was 2.2, 14.7 and 23.9 g/day ( $P < 0.002$ ), respectively. Fecal N was 1.5 for ST, 4.8 for GH, and 5.1 g/day for ALF ( $P < 0.002$ ). Urine N excretion was 6.3 and 6.2 g/day for ST and GH, increasing to 13.6 g/day for ALF ( $P < 0.02$ ). Nitrogen retained was  $-5.4$ , 3.7 and 5.2 g/day for ST, GH and ALF, respectively, with an age and diet  $\times$  age response ( $P < 0.01$  and 0.05, respectively). Plasma glucose was not different for forage or age, averaging 7.6 mmol/L. Lactate was lowest for GH (0.70 mmol/L), with ST and ALF having similar concentrations (0.87 and 0.96 mmol/L;  $P < 0.07$ ). NEFA concentrations were highest for ST (398  $\mu\text{mol/L}$ ) and similar for GH and ALF (204 and 201  $\mu\text{mol/L}$ ;  $P < 0.003$ ). Plasma urea N concentrations were similar for ST and GH (4.3 and 4.9 mmol/L) increasing to 8.1 mmol/L for ALF ( $P < 0.001$ ). Plasma creatinine was higher for ST (250  $\mu\text{mol/L}$ ) than GH and ALF (214 and 205  $\mu\text{mol/L}$ ;  $P < 0.0001$ ). Sodium and calcium concentrations were lower for ST than GH and ALF ( $P < 0.06$  and 0.002, respectively), while potassium and chloride were not different across forages. Metabolite temporal patterns fluctuated over the 24 h period with glucose, lactate, and  $\alpha$ -amino N increasing and NEFA concentration decreasing postprandially. Crude N maintenance requirement was calculated to be 0.84, 0.63, 0.80 and 0.51 g/W<sup>0.75</sup> for AG1, AG2, AG3 and AG4, respectively. Overall N requirement was calculated to be 0.60 g/W<sup>0.75</sup>. These data demonstrate the effects of feeding forages of varying quality on whole-body N utilization, temporal blood metabolite and electrolyte patterns and a possible age effect on maintenance N requirements.

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**Keywords:** Alpaca; Blood metabolites; Blood electrolytes; Nitrogen balance; Nitrogen requirements

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## 1. Introduction

Approximately 2% of the world's South American camelid population is found outside South America and the number is ever increasing as their popularity increases. Some research has been conducted to address nutrition, reproduction and health issues specific to these animals, but there is still a considerable amount of information needed. Data presented in the literature have been obtained from all over the world at various altitudes or information is extrapolated from requirements of goats, sheep and cattle (Carmalt, 2000; Fowler, 1998; San Martin and Bryant, 1989). As an example, present protein requirement values outlined by Carmalt (2000) come from data obtained from alpacas on the Peruvian Altiplano. The accuracy of the data is not in question, but San Martin and Bryant (1989) summarized from the literature that camelids are more efficient at higher altitudes. This was further emphasized by López and Raggi (1992) in their review, further determining that a more appropriate value to use was digestible protein.

Engelhardt et al. (1974) demonstrated that the energy requirement of llamas is lower than that in sheep and cattle demonstrating a difference between ruminants and camelid pseudo ruminants. Studying the digestibility of various feedstuffs, Dulphy et al. (1997) showed that llamas had a higher DM and NDF digestibility than sheep when fed poor quality roughages, but were similar to sheep when fed high quality roughages. Continued efforts are needed to address camelid nutrition issues at lower elevations.

The objectives of this experiment were to characterize the temporal pattern of blood metabolites and electrolytes in male alpaca fed twice daily and to determine the effects of feeding forages of differing quality and protein quantity on N utilization, blood metabolites, and electrolytes in alpaca of different ages.

## 2. Materials and methods

### 2.1. Animals

Sixteen intact male alpaca consisting of four age groups (AG1,  $16 \pm 4.4$  months,  $44.3 \pm 9.2$  kg; AG2,  $25 \pm 1.8$  months,  $51.7 \pm 2.3$  kg; AG3,  $35 \pm 1.1$  months,  $64.7 \pm 15.6$  kg; and AG4,  $60 \pm 12.0$  months,

$67.0 \pm 8.2$  kg) were housed in metabolism crates in an environment of  $20^\circ\text{C}$  with 12:12 h on:off lighting cycle. The animals were allowed to become accustomed (acclimation period) to the metabolism crates for 2 weeks prior to initiating the experiment. During the acclimation period and throughout the experiment, the alpacas were removed from metabolism crates and exercised for 30 min twice daily. Prior to being put in the metabolism crates, and during the acclimation period, the alpaca were fed grass hay (late-bloom Tall Fescue, *Festuca arundinacea*). The alpacas were fed ad libitum twice daily at 12-h intervals, providing 2/3 of the daily feed at the 08:00 h feeding and the remaining 1/3 at the 20:00 h feeding. This was done to accommodate the eating patterns of alpaca, since these animals eat the majority of their feed during the day (personal observation). Water was available ad libitum.

### 2.2. Treatments

The experimental design administered forage treatments randomly to four repetitions of animals, with each age group represented in the replicate. Treatments consisted of three forages: wheat straw (ST), grass hay (GH; late-bloom Tall Fescue, *F. arundinacea*) and alfalfa hay (ALF; mid-bloom, *Medicago sativa*). Forage chemical composition was determined at a certified forage lab (DHI Forage Testing Laboratories, Dairy One Inc., Ithaca, NY) using wet chemistry procedures (Table 1). Treatment periods were

Table 1  
Forage composition<sup>a</sup>

Component	Forage (% DM)		
	Straw	Grass hay	Alfalfa hay
DM	93.2	91.1	90.7
CP	4.0	11.8	16.0
NDF	74.6	62.2	51.5
ADF	42.6	39.2	36.6
Fat	2.5	3.5	3.7
Ash	11.8	10.1	10.8
Ca	0.30	0.46	1.00
P	0.14	0.23	0.25
Na	0.08	0.04	0.01
K	2.16	2.31	2.64
TDN	46	57	55

<sup>a</sup> Forage composition was determined by DHI Forage Testing Laboratories, Dairy One Inc., Ithaca, NY using wet chemistry procedures and are expressed as a percent of DM.

for 14 days, with days 1–7 for diet adjustment and days 8–14 for data collection. A harness system fitted with a fecal collection bag and a urine funnel were put on the alpaca the day prior to starting the collection period. Urine was collected under continuous vacuum into a container containing 50 ml 12 M sulfuric acid. During the data collection period (days 8–14), daily feed intake was measured, feed refusal, fecal output and urine quantity were determined, and each collected for later analysis. Feed refusal and feces were dried at 100 °C, composited by animal, and stored for further analysis. Urine volume was recorded, composited by animal, and an aliquot frozen for later analysis. Composite dry feed samples, feed refusal and fecal samples were ground using a Wiley Mill (Arthur A. Thomas Co., Philadelphia, PA) with a 1 mm screen. Nitrogen (N) content was determined for feed, feed refusal, fecal and urine samples by the Kjeldahl method (AOAC, 1990).

### 2.3. Blood profile

On day 14, blood samples were collected over a 24-h period via indwelling jugular venous catheters (Micro-Renathane®, Braintree Scientific, Braintree, MA). Samples were obtained at 30 min intervals for the first 6 h, hourly for the next 6 h, and every 2 h for the remaining 12 h. The time 0 sample was taken prior to the 08:00 feeding. Fresh feed was immediately offered post sampling. Plasma was obtained by centrifugation at 2400 × g for 20 min, aliquotted and frozen at –20 °C for later analysis. An aliquot of whole blood was deproteinized with 20% trichloroacetic acid, centrifuged as described previously, and the supernatant frozen at –20 °C for later analysis of α-amino N. Plasma samples were analyzed for glucose, urea N, creatinine, sodium, potassium, and chloride using a NOVA 16 blood chemistry analyzer (Nova Biomedical, Waltham, MA). Non-esterified fatty acids (NEFA) were determined using a NEFA-C kit (#990-75401, Wako Chemical USA Inc., VA). Plasma lactate and calcium were determined using a Chiron 860 analyzer (Bayer Diagnostics, Indianapolis, IN). A modified version of Technicon's (Method #512-77T; Technicon Industrial Systems, Tarrytown, NY) α-amino N method was used to determine the whole blood α-amino N concentration using the deproteinized samples.

### 2.4. Statistics

The nitrogen balance (intake and excretion) data were analyzed using a linear mixed model with age, forage, and age by forage interaction as fixed effects. Replicates, animals within replicates, and the replicate by forage interaction were specified as random effects. Because the data were unbalanced (one animal was eliminated from the straw diet due to health concerns), the Kenward–Roger adjustment for denominator degrees of freedom was used in hypothesis tests of the fixed effects. The age by forage interaction was dropped from the model if it was negligible (non-significant,  $P > 0.05$ ). Least squares means for levels of the age and forage factors were calculated and compared using unadjusted *t* tests. The SAS (SAS, Inst., Cary, NC) procedure MIXED was used for all calculations.

Blood chemistry variables were analyzed as described above including the covariance structure for the repeated measurements over time for each animal–forage combination specified as the spatial-power structure, with correlation depending on the time interval between measurements. The SAS procedure MIXED was used for all blood chemistry calculations.

## 3. Results

One animal from AG1 was not included due to aberrant data. Dry matter intake (Table 2) differed between the three forages, being 212, 678 and 715 g/day ( $P < 0.002$ ) for ST, GH and ALF, respectively. As observed previously in other metabolism studies with

Table 2  
Effects of feeding forages of varying quality and CP concentration on whole-body N utilization in alpacas

	Forage				<i>P</i> < 0.1
	Straw	Grass	Alfalfa	S.E.M.	
DM intake (g/day)	212	678	715	88	0.002
N intake (g/day)	2.2	14.7	23.9	2.9	0.002
Fecal N (g/day)	1.5	4.8	5.1	0.6	0.002
Urine N (g/day)	6.3	6.2	13.6	1.6	0.02
UN%TN <sup>a</sup> (%)	78.7	54.1	72.0	3.1	0.001
N retained (g/day)	–5.4	3.7	5.2	2.1	0.001
DM digestibility	25.9	61.9	63.9	12.4	0.07
N digestibility	40.8	68.1	78.6	4.0	0.001

<sup>a</sup> Urine N excreted as a percentage of total N excreted.

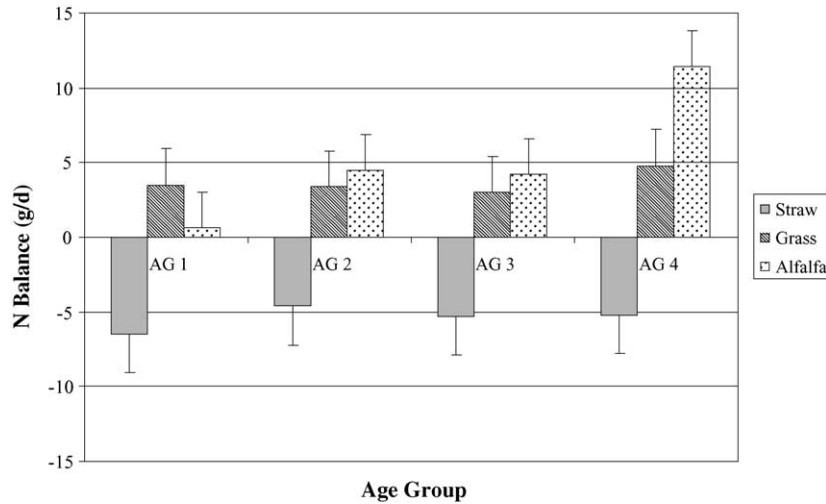


Fig. 1. Effect of feeding forages of differing protein content on N balance in male alpaca of four age groups (forage,  $P < 0.0001$ ; age,  $P < 0.01$ ; forage  $\times$  age,  $P < 0.05$ ; S.E.M. 2.4).

alpacas, these animals ate most of their feed allocation during the daytime, between the 08:00 and 20:00 feeding times, and they ate very little during the night time. Digestibility of DM was different ( $P < 0.07$ ) between the ST and the GH and ALF forages (40.8, 68.1 and 63.9%, respectively). Age had no effect on DM digestibility.

### 3.1. Nitrogen utilization

Whole-body N data are presented in Table 2. No age effect was noted and thus the data are presented

for the forage effect only. Nitrogen intake increased from 2.6 g/day for ST to 15.0 and 24.6 g/day for GH and ALF ( $P < 0.001$ ), respectively. The ST consumption was lower than anticipated which exacerbated the N intake differences. ST fecal N excretion was lower ( $P < 0.0001$ ) than that for GH and ALF, while ST and GH urine N excretion was 6.3 and 6.2 g/day, less ( $P < 0.0001$ ) than the 13.7 g/day for ALF. Nitrogen digestibility was also affected by diet ( $P < 0.0001$ ), 40.1, 68.0 and 78.5% for ST, GH and ALF, respectively. When alpacas consumed the ST forage they became negative in N balance at  $-5.3$  g/day, then increased

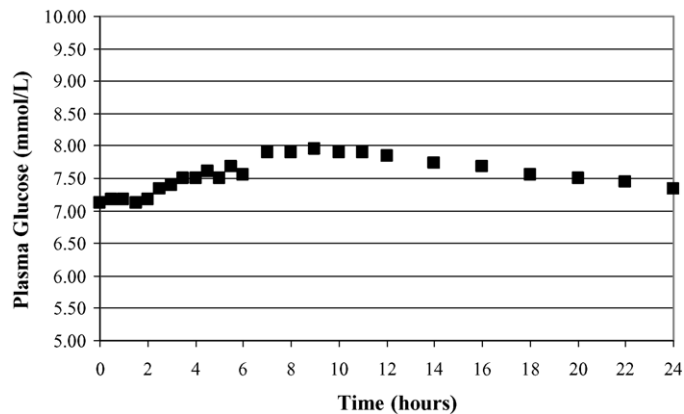


Fig. 2. Effect of feeding on the temporal pattern of plasma glucose concentration in alpaca. The alpaca were fed at time 0 and 12 h. Time was significant at  $P < 0.003$ .

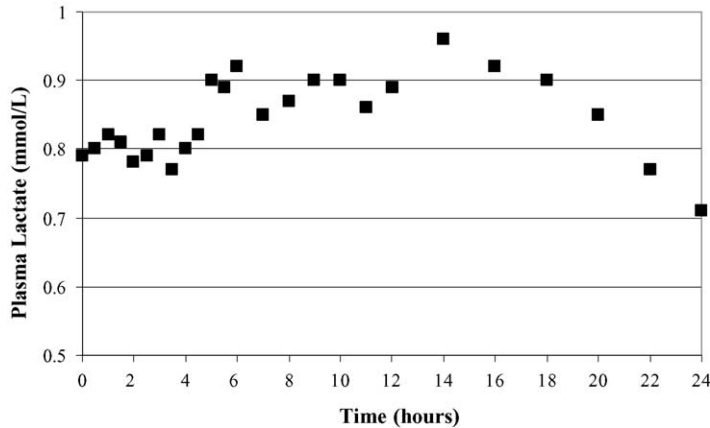


Fig. 3. Effect of feeding on the temporal pattern of plasma lactate concentration in alpaca. The alpaca were fed at time 0 and 12 h. Time was significant at  $P < 0.08$ .

( $P < 0.0001$ ) to 3.9 and 5.8 g/day for GH and ALF forage treatments, respectively. The age and age  $\times$  forage interactions for N retention were significant at  $P < 0.01$  and  $P < 0.05$ , respectively (Fig. 1).

3.2. Blood metabolites and electrolytes

The blood metabolite and electrolyte data are presented in Table 3 as means of all the samples across the 24 h sampling period. Results are presented for forage by age with associated significance. Temporal patterns for significant metabolite and electrolytes are presented in Figs. 2–7.

Plasma glucose concentrations were not affected by forage or age, ranging from 7.1 to 8.1 mmol/L across the forage and age groups. The temporal pattern for glucose over the 24-h period is presented in Fig. 2. Time was the only significant main effect ( $P < 0.003$ ). Glucose concentration increased from 7.2 mmol/L at time 0 to approximately 7.9 mmol/L at hour 7. Evening feeding did not result in a similar pattern, in fact glucose levels returned to 7.3 mmol/L.

Lactate concentrations were significant for forage and for the forage  $\times$  age interaction ( $P < 0.07$  and  $P < 0.01$ , respectively). Temporal pattern for lactate (Fig. 2) was significant for time at  $P < 0.08$ .

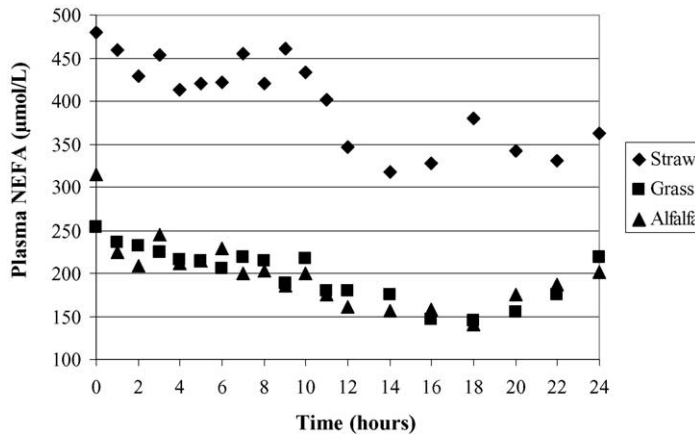


Fig. 4. Effect of feeding three forages of differing crude protein content on the temporal pattern of plasma non-esterified fatty acid (NEFA) concentration in alpacas. The alpacas were fed at time 0 and 12 h. Time and time  $\times$  forage were significant at  $P < 0.001$  and 0.06, respectively.

Table 3

Effects of three forages of differing protein content on plasma metabolite and electrolyte concentrations in alpaca of four age groupings

	Age group	Forage			S.E.M.	$P < 0.10$		
		Straw	Grass	Alfalfa		Forage	Age	F × A
Glucose (mmol/L)	1	7.7	7.5	7.1	0.7	NS	NS	NS
	2	7.6	8.0	8.0	0.7			
	3	7.3	7.2	7.0	0.7			
	4	8.1	7.5	8.0	0.7			
Lactate (mmol/L)	1	0.87	0.63	1.18	0.12	0.07	NS	0.01
	2	0.81	0.78	0.83	0.11			
	3	0.91	0.71	0.94	0.11			
	4	0.88	0.69	0.89	0.11			
NEFA ( $\mu\text{mol/L}$ )	1	424	205	211	45	0.003	NS	0.05
	2	372	214	176	44			
	3	382	199	248	44			
	4	415	184	179	44			
Urea N (mmol/L)	1	4.4	5.4	9.0	0.8	0.001	0.06	NS
	2	3.0	3.6	5.8	0.8			
	3	5.6	5.7	9.3	0.8			
	4	4.3	4.7	8.2	0.8			
Creatinine (mmol/L)	1	256	212	203	26	0.0001	NS	0.001
	2	265	203	150	26			
	3	230	221	247	26			
	4	247	221	221	26			
$\alpha$ -Amino N ( $\mu\text{mol/L}$ )	1	5.0	4.6	4.5	0.5	NS	NS	NS
	2	6.1	5.8	5.5	0.5			
	3	4.6	4.1	4.3	0.5			
	4	4.9	4.6	4.5	0.5			
Sodium (mmol/L)	1	147	158	153	2.7	0.06	NS	0.003
	2	150	158	151	2.6			
	3	154	156	155	2.6			
	4	152	157	159	2.6			
Potassium (mmol/L)	1	4.6	5.0	4.7	0.2	NS	NS	NS
	2	4.7	4.7	4.6	0.2			
	3	4.8	5.1	4.8	0.2			
	4	4.7	4.8	4.7	0.2			
Chloride (mmol/L)	1	117	125	120	1.9	NS	NS	0.001
	2	121	127	122	1.9			
	3	124	124	123	1.9			
	4	122	125	127	1.9			
Calcium (mmol/L)	1	0.91	1.00	1.05	0.07	0.002	NS	NS
	2	0.96	1.06	1.09	0.07			
	3	0.97	1.19	1.06	0.06			
	4	0.97	1.00	0.92	0.07			

The overall NEFA concentration for ST was higher ( $P < 0.003$ ) for the forage effect at between 372 and 424  $\mu\text{mol/L}$ , decreasing to 179–248  $\mu\text{mol/L}$  for GH and ALF. Age was not significant,

while the forage  $\times$  age interaction was significant at  $P < 0.05$ . Temporal NEFA concentrations (Fig. 3) were significant for time ( $P < 0.001$ ) and the time  $\times$  forage interaction ( $P < 0.06$ ) showed

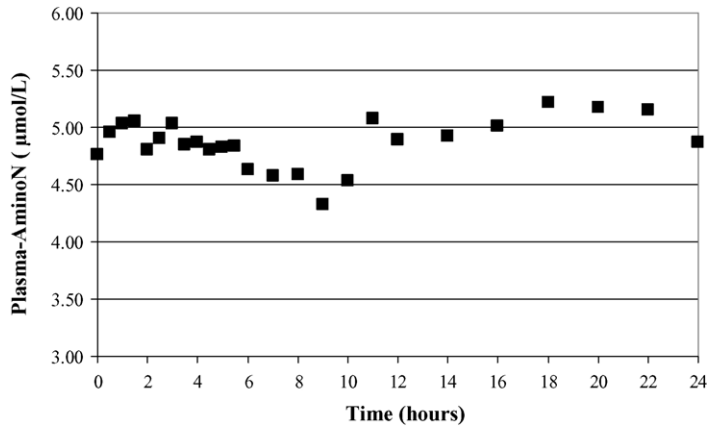


Fig. 5. Effect of feeding on the temporal pattern of plasma  $\alpha$ -amino N concentration in alpaca. The alpaca were fed at Time 0 and 12 h. A time effect was significant at  $P < 0.0001$ .

a postprandial decrease in plasma concentrations.

Overall plasma urea N (PUN) was similar for ST and GH, but was higher for the ALF forage ( $P < 0.001$ ). The AG2 group exhibited lower PUN concentrations across all forages than the other three age groups (Table 3). Temporal PUN pattern (data not shown) was not different for time, age or the interaction. Plasma creatinine was affected by diet ( $P < 0.0001$ ), with ST having the highest concentrations and ALF the lowest. Age was not significant, but the forage  $\times$  age interaction was at  $P < 0.001$ . Temporal plasma creatinine pattern (data not shown) was not significant for time, age or the interac-

tion. The  $\alpha$ -amino N concentrations were not affected by forage or age, while a time effect was noted across the 24-h period (Fig. 4;  $P < 0.001$ ) decreasing postprandially to 10 h then increasing to  $4.9 \mu\text{mol/L}$  at the 24 h sample.

Plasma sodium concentrations were higher ( $P < 0.06$ ) for GH than ST or ALF and also showed a forage  $\times$  age effect ( $P < 0.003$ ). There was no plasma sodium temporal pattern effect (data not presented) noted. Plasma potassium was not affected by forage or age, while there was a time effect (Fig. 5;  $P < 0.001$ ),  $\text{K}^+$  decreasing after the morning feeding then rising to a peak level at hour 16 before returning to the

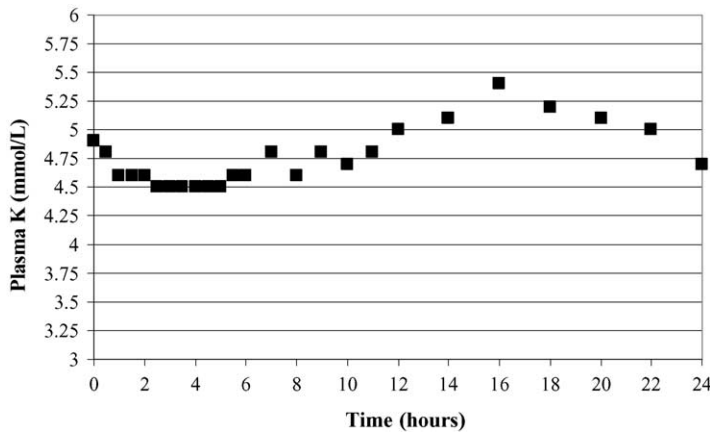


Fig. 6. Effect of feeding on the temporal pattern of plasma potassium (K) concentration in alpaca. The alpaca were fed at time 0 and 12 h. An hour effect was noted at  $P < 0.001$ .

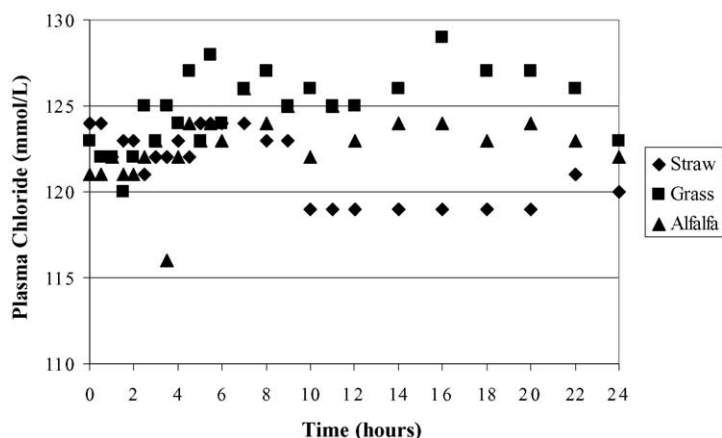


Fig. 7. Effect of feeding three forages of differing crude protein content on the temporal pattern of plasma chloride concentration in alpaca. The alpaca were fed at time 0 and 12 h. The time  $\times$  forage interaction was significant at  $P < 0.06$ .

0 h level of 4.9 mmol/L. Plasma chloride paralleled the plasma sodium, and resulted in a forage  $\times$  age interaction ( $P < 0.001$ ) and a forage  $\times$  time interaction (Fig. 6;  $P < 0.06$ ). Plasma calcium was higher for the GH and ALF ( $P < 0.002$ ) forages than ST, but showed no temporal changes over the 24-h period (data not shown).

#### 4. Discussion

The forages used in this experiment were chosen for their overall nutritional quality and quantity of crude protein. Good quality wheat straw, anticipated to provide a quantity of protein below that required by the alpacas was fed (Carmalt, 2000; male alpaca at 50 kg BW). The forage quality on the South American Altiplano can decrease to approximately 3% crude protein (Walter Bravo, personal communication) during the dry season. We used wheat straw with a CP of 6.6% to approximate the level of forage protein found where alpacas are indigenous in South America. The grass hay was estimated to meet the protein requirement of the alpacas at any geographical location, while the alfalfa was chosen to provide excess protein beyond their nutritional needs. By choosing these three forages, we were able to show an incremental increase in protein intake versus protein retention and provide the data needed to provide an estimate of protein requirement.

Palatability was assumed to be the reason for the significantly lower DM intake of ST. In subsequent studies where we have fed barley straw or barley hay, we have found DM intake in alpacas to decrease in comparison to grass hay. The decrease in DM intake of ST exacerbated the low protein availability to well below that predicted to be present on the Altiplano. This reduced intake further accentuated the difference in N intake between treatments.

Dry matter digestibility was not different between the three forages. Contrary to studies with other species, although straw did have a trend toward lower digestibility, it was not significant ( $P < .07$ ). Hintz et al. (1973) demonstrated that llamas more efficiently digested poor quality forages than sheep, but not when fed higher quality forages. Heller et al. (1986) demonstrated in llamas that small particle and large particle retention times were 52.0 and 59.9 h, respectively.

Available N, expressed as the difference between N intake and fecal N as a percent of N intake, resulted in a higher amount of N from ALF apparently being absorbed by the gut, with 79, 67 and 32% for ALF, GH and ST, respectively. Urine N excretion and PUN concentrations were similar for ST and GH, but both were lower than for ALF (see Tables 2 and 3). A higher percentage of the total N excreted for ST and ALF was in the urine (78.7, 54.1 and 72.0% for ST, GH and ALF, respectively; see Table 2, UN%TN: urine N excreted as a percentage of total N excreted). This pattern of urine N excretion is indicative of the extremely low N intake

for ST and the extremely high intake for ALF. PUN concentrations were similar for the ST and GH forages and highest for the ALF forage, while creatinine was highest for the lower quality ST, but similar for the GH and ALF forages. Circulating  $\alpha$ -amino N concentrations were not different across forages or ages.

The low total N excretion was expected when alpaca consumed ST as a result of their low intake. When coupled with the urea N value and percent of urine N excreted, the increased level of plasma creatinine and corresponding negative N balance are indicative of catabolism of body protein reserves to meet energy requirements. On the other hand, the high N intake of ALF coupled with high urine N excretion, high urea N concentrations and low plasma creatinine levels demonstrate feed protein catabolism and excretion of the excess N. One would expect the ST urea N levels to be higher due to amino acid catabolism to accommodate energy needs. Hinderer and Engelhardt (1975) demonstrated that llamas had a lower renal urea N excretion than sheep. They further concluded that urea N turnover in llamas is less than in sheep, 3% versus 12%, respectively. Farid et al. (1979) concluded that nitrogen conservation is due to a decrease in fecal and urine N excretion.

Glucose, lactate and NEFA concentrations were determined to better understand the alpaca's energy status when consuming each forage at each age grouping. Glucose levels were maintained across treatments and were similar to those presented by Burton et al. (2003) and Fowler (1998). NEFA concentrations were highest for the low quality ST forage and lowest for the high quality ALF forage, indicating the need of lipid mobilization to meet energy requirements during consumption of the ST treatment in an effort to maintain euglycemia. Rasmussen and Wolfe (1999) describe a fatty acid–glucose cycle, where an increase in plasma NEFA concentrations results in a decrease in glucose oxidation, in effect resulting in glucose sparing. On the other hand, Cebra et al. (2001) determined from glucose tolerance testing that llamas and alpacas have a slower glucose clearance than other ruminant animals that may be due to insulin resistance. They further speculated that this slow glucose clearance could be an adaptation to the harsh Altiplano environment resulting in a glucose sparing affect. This would shift glucose from insulin-dependant tissues (muscle) to tissues like the brain, forcing the insulin-dependent tissues to utilize NEFA's

for energy. Temporal patterns of plasma glucose, lactate and NEFA were affected by feeding, where glucose and lactate increased and NEFA concentrations decreased. There was not a temporal forage effect for glucose or lactate but ST NEFA levels were almost twice that of the GH and ALF forages. These findings demonstrate that alpacas are able to regulate glucose and maintain consistent euglycemia even though NEFA levels indicate the animals are in negative energy balance when consuming the ST forage, eliciting a lipolytic response. This lipolytic response could be an effort by the animal to meet insulin-dependent tissue needs. Further research is needed to determine the major fuels used by various camelid tissues.

Plasma electrolyte concentrations were similar to those reported previously in the literature (Burton et al., 2003; Fowler, 1989). Plasma calcium concentrations were consistent with the levels found in the three forages, with ST having the lowest and ALF the highest levels. Temporal variation in plasma potassium and chloride concentrations appeared to be affected by feeding, although a more defined experiment is needed to elucidate the cause.

Nitrogen requirement was determined for each age group by regressing N retained against N intake per unit of metabolic BW ( $\text{kg W}^{0.75}$ ; Preston, 1966). Maintenance requirement was determined to be the zero intercept. Our data indicate that the N maintenance requirement was 0.84, 0.63, 0.80 and 0.51 g crude N/ $\text{W}^{0.75}$  for AG1, AG2, AG3 and AG4, respectively. Calculating the maintenance requirement ignoring age across all animals, we determined the N requirement to be 0.60 g crude N/ $\text{W}^{0.75}$ . Huasasquiche (1974) determined maintenance digestible N requirement to be 0.38 g/ $\text{W}^{0.75}$  based on eight male alpacas of non specified age. Huasasquiche (1974) conducted this research on the Peruvian Altiplano. San Martin and Bryant (1989) summarized that camelids on the Altiplano are more efficient at feed utilization than similar species of camelids at sea level. This being the case, disparity between Huasasquiche's data and ours could be due to this efficiency phenomenon and the difference in altitude. If we use the standard CP to digestible protein (DP) conversion factor of 0.8, our values range from 0.67 for AG1 to 0.41 g/ $\text{W}^{0.75}$  for the AG4 group. Our calculations indicate that the alpaca in this study, under these conditions, had a higher maintenance protein requirement than the general value indicated by Huasasquiche

(1974). Carmalt (2000) combined the protein requirement value of Huasasquiche (1974) with DE (derived from llama data) to get the equation of:

$$\text{CP(g)} = 31\text{g} \times \text{DE (Mcal)}. \quad (1)$$

For a growing alpaca, Carmalt (2000) suggested an additional 1.78 Mcal DE/day. For a juvenile alpaca weighing 40 kg with a daily DE maintenance requirement of 1.64 Mcal DE/day, the addition of 1.78 Mcal DE for growth has a CP requirement of 106 g CP/day. Eq. (1) was assumed to be calculated by converting the ME requirement of llamas published by Engelhardt and Schneider (1977) of 61 Mcal/W<sup>0.75</sup> ME to DE (ME  $\times$  1.22) then dividing by the 2.38 g CP (0.38 g N  $\times$  6.25). Substituting our maintenance value of 0.60 g N results in a requirement of 68 g CP/day. Using the same data from Huasasquiche (1974). López and Raggi (1992) determined that DP was a better estimate and used a conversion of 0.68 CP per unit DP. This increased the 0.38 g N/W<sup>0.75</sup> to 0.56 g DP N/W<sup>0.75</sup>. López and Raggi (1992) further explained that altitude must be considered due to an increase in efficiency at the higher altitude as described by San Martín and Bryant (1989). Based on these discrepancies, further research is needed to estimate the protein requirement of alpacas at lower altitudes and to address the energy:protein interaction in alpacas of varying ages. In addition, there is no data comparing llama and alpaca protein or energy requirements. Extrapolated data from llamas, although probably the best alternative, may not be appropriate. Further research in this area is also needed.

## 5. Conclusions

These data demonstrate the effects of feeding three forages of varying quality on whole-body N utilization and metabolite and electrolyte temporal patterns in alpacas. Low quality, low protein content forage (ST) resulted in a negative N balance, and protein and lipid mobilization with subsequent catabolism to maintain adequate circulating glucose and  $\alpha$ -amino N levels. High quality, high protein content such as that found in alfalfa resulted in the excretion of excess dietary N through urinary urea. These data characterized temporal metabolite and electrolyte patterns and indicated

that younger alpacas may have a higher maintenance protein requirement than the previously cited value of 0.38 g/W<sup>0.75</sup> (Huasasquiche, 1974). Further examination is needed to elucidate the protein requirement and the protein:energy interaction of alpaca.

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