Puberty and ovulation rate of Romanov, Dorper, and their crosses during the first breeding season

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Six Dorper (D), 21 Romanov (R), 50 3/4D × 1/4R, 53 1/2D × 1/2R, and 46 1/4D × 3/4R ewe lambs, born over a six-week period in October/November 1989, were teased twice daily from weaning during 1990 until they showed no further signs of oestrus. Ovulation rate was determined laparoscopically three to four days after the cessation of oestrus. Age of the dam had a significant ($P < 0.01$) effect on mass and age at first oestrus, but had no significant effect on ovulation rate of the ewe lambs. Dorper ewe lambs were the heaviest and oldest at the end of the breeding season, but none completed three oestrous cycles. Fifty per cent of the 3/4D × 1/4R, 66% of the 1/2D × 1/2R, 74% of the 1/4D × 3/4R, and 71% of the Romanov genotypes completed three oestrous cycles. Genotype had a significant ($P < 0.01$) effect on age and mass at first oestrus and also on ovulation rate. An increase in the percentage Romanov genes resulted in a decrease in ewe mass and an increase in ovulation rate. The mean age of ewe lambs over the first three oestrous cycles decreased up to the 1/2D × 1/2R genotype, but increased again with a further accruement of Romanov genes.

Ses Dorper(D)-, 21 Romanov(R)-, 50 3/4D × 1/4R-, 53 1/2D × 1/2R-, en 46 1/4D × 3/4R-ooilammers, gebore oor 'n periode van ses weke in Oktober/November 1989, is tweemaal daagliks gedurende 1990 gekoggel totdat geen teken meer van estrusaktiwiteit waargeneem is nie. Drie tot vier dae later is ovulasietempo van die ooie wat estrus vertoon het, laparoskopies bepaal. Ouderdom van die moeder het 'n betekenisvolle ($P < 0.01$) invloed op massa en ouderdom by eerste estrus van die lammers gehad, maar nie op ovulasietempo nie. Dorperlammerooie was die swaarste en die oudste aan die einde van die teelseisoen, maar geen Dorperooi het drie estrussiklusse voltooi nie. Drie estrussiklusse is wel deur 50% van die 3/4D × 1/4R-, 66% van die 1/2D × 1/2R-, 74% van die 1/4D × 3/4R- en 71% van die Romanov-genotipes voltooi. Genotipe het 'n betekenisvolle ($P < 0.01$) invloed op ouderdom en massa by eerste estrus, en op ovulasietempo gehad. 'n Verhoging in die persentasie Romanovgene het gelei tot 'n verlaging in ooimassa en 'n toename in ovulasietempo. Die gemiddelde ouderdom van ooilammers oor die eerste drie estrussiklusse het afgeneem tot by die 1/2D × 1/2R-genotipe, waarna dit weer toegeneem het met 'n verdere toename in Romanov-gene.

Keywords: Crosses, Dorper, ovulation rate, puberty, Romanov.

Lifetime lamb production can be increased by reducing the unproductive periods in an ewe's lifetime. One of the most unproductive periods is from weaning until first breeding. Hulet *et al.* (1969) have demonstrated that ewe lambs reaching puberty during the first breeding season possess a higher production potential than other ewe lambs, even if they are not bred during that first year. Under South African conditions, ewes are normally first bred between 12 to 18 months of age which implies a relatively long unproductive period. This unproductive period can be reduced substantially through crossbreeding with early maturing sheep breeds to improve lifetime reproduction.

The Romanov is well known for its exceptionally high ovulation rate and its early sexual maturity (Ricordeau *et al.*, 1990). In this respect it could make a valuable contribution in developing early maturing animals for commercial purposes. This study was initiated in order to determine to what extent early maturity and ovulation rate can be increased by increasing the proportion of Romanov genes in crosses with the Dorper.

Six Dorper (D), 21 Romanov (R), 50 3/4D × 1/4R, 53 1/2D × 1/2R, and 46 1/4D × 3/4R ewe lambs, born over a six-week period in October/November 1989, were used in this study. The 3/4D and 3/4R crosses were developed by backcrossing F_1 ewes to Dorper and Romanov rams, respectively. The 1/2D × 1/2R crosses were comprised of reciprocal crosses between the Romanov and Dorper and of crosses between F_1s mated *inter se*. Only conformationally sound ewes were used in this experiment. Forty-five of these ewe lambs were born as singletons, 75 as twins, 47 as triplets and 9 as quadruplets. At birth the age of their dams varied between one and 10 years.

Ewes were managed together from birth until the end of the experiment. Teasing of ewe lambs commenced after weaning in January 1990. Ewes were teased every morning with the aid of vasectomized rams and all ewes which exhibited oestrus were removed from the flock and weighed. These ewes were teased separately twice daily, in the morning and in the afternoon, until they showed no further signs of oestrus. Ovulation rate of each of these ewes was determined laparoscopically three to four days after the cessation of oestrus. The ewes were then returned to the main flock. The number of corpora lutea was used as an indication of ovulation rate. Ewes were subjected to this routine for three oestrous cycles. At the fourth oestrous cycle, ewes were mated with fertile rams. Ewes that did not exhibit three oestrous periods by the end of June were mated, irrespective of the number of oestrous cycles exhibited.

The data were analysed with the LSMLMW computer program of Harvey (1987). Age and mass are continuous variables, whereas ovulation rate is a discrete character with an assuming underlying polygenic inheritance (Turner & Young, 1969). Harvey (1982), however, indicated that least-squares means procedures may be used to analyse discrete data.

The following model was used:

$$Y_{ijkl} = \mu + a_i + c_j + d_k + e_{ijkl}$$

where Y_{ijkl} = the observed value of a given dependent variable,
μ = the overall mean,
a_i = the fixed effect of the i^{th} genotype,
c_j = the fixed effect of the j^{th} age of the dam,
d_k = the fixed effect of the k^{th} type of birth, and
e_{ijkl} = the random error.

The effect of genotype (5 levels) and age of the dam (10 levels), and type of birth (4 levels) on mass, age and ovulation rate at first oestrus and over three oestrous cycles, was determined. In the initial model, the three different F_1 types were identified separately to make provision for possible differences owing to heterosis effects. No significant differences were, however, found after which the data of the different F_1 types were pooled. All possible interactions were included in the initial model but, since none was found to be significant, they were left out in the final model. A covariance analysis was also carried out to adjust for the effect of mass and age of the ewe in order to determine the effect of genotype on ovulation rate.

Nutrition, date of birth, increasing or decreasing daylight length and temperature may influence the occurrence of oestrus in sheep (Dzakuma & Harris, 1989). As the experimental animals were born over a six-week period and managed together, it was assumed that all animals were influenced by these external factors to the same extent. The least-squares means and standard errors of the least-squares means (lsm ± *SE* of lsm) of ovulation rate, age and mass of ewe lambs over their first three oestrous cycles are indicated in Table 1.

Table 1 The effect of age of the dam and birth status on the mean ovulation rate, age and mass of ewe lambs over their first three oestrous cycles (lsm ± *SE* of lsm)

Age of dam (years)	n	Ovulation rate (Corpora lutea)	Age (d)	Mass (kg)
1	1	1.6 ± 0.7	257 ± 14^{ba}	39 ± 4.3^{b}
2	20	1.5 ± 0.2	233 ± 4^{a}	30 ± 1.0^{a}
3	30	1.4 ± 0.1	233 ± 3^{a}	32 ± 0.9^{a}
4	9	1.4 ± 0.2	230 ± 5^{a}	36 ± 1.4^{b}
5	8	1.6 ± 0.3	239 ± 5^{bc}	30 ± 1.6^{a}
6	10	1.6 ± 0.2	237 ± 5^{ac}	29 ± 1.5^{a}
7	7	1.1 ± 0.3	246 ± 6^{b}	30 ± 1.7^{a}
8	6	1.3 ± 0.3	235 ± 7^{a}	31 ± 1.8^{a}
9	1	1.9 ± 0.7	242 ± 14^{ba}	36 ± 4.3^{ba}
10	16	1.3 ± 0.2	252 ± 4^{b}	29 ± 1.2^{a}
Birth status				
Singletons	27	1.7 ± 0.2	229 ± 3^{a}	34 ± 1.0^{a}
Twins	47	1.5 ± 0.2	238 ± 3^{b}	32 ± 1.0^{b}
Triplets	29	1.2 ± 0.2	241 ± 4^{b}	30 ± 1.0^{c}
Quadruplets	4	1.4 ± 0.4	257 ± 7^{c}	32 ± 2.1^{abc}

[a—c] Means with different superscripts in the same column and variable, differ significantly ($P < 0.05$) from each other.

Although age of the dam had a significant ($P < 0.01$) effect on mass and age at first oestrus, no clear trend could be noted for mass. Ewes of six-year-old dams were on average the lightest with a mean mass of 29 kg over three cycles. A clear trend was, however, noticed for age at first oestrus. Contrary to expectation, a daughter of a one-year-old dam had the highest average mass of 39.2 kg, and was also the oldest. If this single ewe is ignored, age at oestrus appears to increase linearly as the dams become older. Ewes born from ten-year-old dams were on average the oldest, i.e. 252 days, at oestrus. In spite of this, age of the dam had no significant effect on ovulation rate.

Birth status of the ewe had no significant effect on ovulation rate, but a highly significant ($P < 0.01$) effect on mass and age over the first three oestrous cycles (Table 1). This was probably due to the fact that singletons normally have a higher growth rate than twins and twins a higher growth rate than triplets, etc., resulting in lambs from multiple births showing oestrus at an older age. If a critical mass does exist before an ewe lamb becomes sexually active, it would appear that singletons reached their critical mass before twins, and twins before triplets. This may have led to ewes from multiple births reaching puberty near the end of the breeding season, which might have reduced their ovulation rate.

Fifteen per cent of the available ewes never showed any signs of oestrus. Of the 109 ewes which exhibited oestrus three times, eighteen (16.5%) did not ovulate on one or more occasions. This, however, is not unusual as it is commonly accepted that ovulation does not always take place after an observed oestrus in pubertal lambs. Edey *et al.* (1977) found that it can vary between 6 and 33%, depending on the breed.

Despite the fact that all the Dorper ewes weighed more than 34 kg in April and were older than 8 months at the end of June, none exhibited oestrus three times. On the other hand, 50% of the 3/4D × 1/4R, 66% of the 1/2D × 1/2R, 74% of the 1/4D × 3/4R and 71% of the Romanov genotypes exhibited oestrus three times. The percentage ewes which exhibited oestrus three times thus increased until the proportion of Romanov genes increased to 75%, after which it declined slightly.

Highly significant ($P < 0.01$) differences were found between genotypes for age, mass and ovulation rate over the first three oestrous cycles. The mean mass of those Dorper ewe lambs which exhibited oestrus once was 39 ± 2.7 kg, which was significantly ($P < 0.01$) higher than the mass of any of the crosses or the Romanov ewes at their first oestrus. Table 2 indicates that the crosses did not differ significantly from each other but were significantly ($P < 0.01$) heavier than the Romanov.

The mean age of ewe lambs over the first three oestrous cycles decreased from 227 days for the 3/4D × 1/4R

Table 2 The effect of genotype on the mean age, ewe mass and ovulation rate over the first three oestrous cycles (lsm ± *SE* of lsm)

Genotype	n	Age (d)	Mass (kg)	Ovulation rate (Corpora lutea)
Dorper (D)[1]	3	213 ± 13	39 ± 2.7	1.0 ± 0.41
3/4D × 1/4R	25	227 ± 4^{a}	34 ± 0.9^{a}	1.1 ± 0.13^{a}
1/2D × 1/2R	34	215 ± 3^{b}	33 ± 0.8^{a}	1.2 ± 0.11^{a}
1/4D × 3/4R	34	221 ± 4^{ab}	33 ± 0.8^{a}	1.7 ± 0.12^{b}
Romanov (R)	15	228 ± 3^{a}	28 ± 0.8^{b}	1.9 ± 0.12^{b}

[a,b] Means with different superscripts in the same column differ significantly ($P < 0.05$) from each other.

[1] Means of first oestrous cycle only.

genotype to 215 days for the 1/2D × 1/2R, after which it increased to 228 days for the Romanov. This pattern indicates that heterosis might be important for this trait and implies that non-additive genes could be involved. This would support the conclusion of Dyrmundsson (1973).

Toteda *et al.* (1987) reported a mean age of 206 ± 4.5 days and a mean mass of 31.1 ± 1.05 kg at puberty in Romanov ewes. Boshoff *et al.* (1975) found that Romanov crosses exhibited oestrus significantly earlier than Karakul ewes. Age and mass of the crosses were significantly lower than those of Karakul ewes. Their results agree with the results of this study in that the crosses were significantly lighter at oestrus than the indigenous breed. In this study, the Dorper ewes were, however, younger at first oestrus than the crosses. It would appear that an increase of more than 50% in the proportion of Romanov genes resulted in a lengthening of the prepubertal period. This is in agreement with results of Dyrmundsson & Lee (1972), Keane (1974), and Quirke (1978) who indicated that a close association exists between body mass and the onset of puberty. The concept of a threshold mass for puberty within a specific management and feeding system is generally accepted by scientists, but is questioned by Baker & Morris (1986). The correlation between age and mass over the three different cycles was negative and very low, viz. –0.17. This may be an indication that the threshold mass was already crossed, after which age and mass at oestrus would appear to be independent.

Ovulation rate, adjusted for ewe mass and age at oestrus, showed a significant ($P < 0.01$) increase with an increase of Romanov genes from 1.1 in the 3/4D × 1/4R up to 1.9 in the Romanov. Ricordeau *et al.* (1978) also found that the number of ovulations increased with an increase in Romanov genes. The ovulation rate found in this study agrees well with that found by Land *et al.* (1973), viz. 1.13 to 2.57, but is lower than the rates reported by Toteda *et al.* (1987) and Ricordeau *et al.* (1978), viz. 2.4 to 3.7, and 2.3 to 2.9, respectively. These trends signify a strong additive inheritance pattern which partly explains why no heterosis is found for ovulation rate in the literature.

The infusion of Romanov genes into a population via crossbreeding advances the onset of puberty, increases ovulation rate and decreases ewe mass.

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Suitability of a lime source high in manganese as a feed ingredient for sheep

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An investigation was conducted to ascertain whether a source of feed lime (Ouplaas lime) high in manganese (5 000 mg Mn/kg) is a safe feed ingredient for sheep. Two levels of Ouplaas lime, 1% and 4%, were included in a sheep finishing diet and compared with another lime source (Kulu lime; 45 mg Mn/kg) which was included at the same levels in the diets. Lambs were fed individually for 69 days. In the final feed mixtures none of the diets contained toxic levels of any minerals. No significant differences between treatments with the same level of lime inclusion occurred in: growth rate, feed intake and utilization, plasma enzyme levels, mineral concentrations in plasma, faeces and kidneys, mineral content of livers, haematology, histopathology of livers and kidneys and bone measurements. It is concluded that the Ouplaas lime, when included at realistic concentrations in diets, poses no risk to the health of sheep.

Ondersoek is ingestel na die veiligheid om 'n voerkalk (Ouplaaskalk) met 'n hoë mangaaninhoud (5 000 mg Mn/kg) aan skape te voer. Die Ouplaaskalk is teen 1% en 4% in 'n vetmestingsrantsoen vir lammers geplaas en vergelyk met 'n ander bron van kalk (Kulukalk; 45 mg Mn/kg), ingesluit teen dieselfde vlakke. Lammers in die vier behandelings is vir 69 dae individueel gevoer en daarna geslag. Die finale rantsoene het geen minerale teen toksiese vlakke bevat nie. Geen statisties-betekenisvolle verskille tussen behandelings wat dieselfde peil kalk bevat het, is waargeneem in: groeitempo, voerinname, voeromsetting, ensiempeile in plasma, konsentrasie van minerale in die plasma, mis en niere, mineraalinhoud van die lewer, haematologie, histopatologie van die lewers en niere en metings op ribmonsters nie. Dit blyk dat Ouplaaskalk, mits dit teen realistiese vlakke in rantsoene gevoeg word, geen gesondheidsrisiko vir skape inhou nie.

Keywords: Feed lime, health, manganese, sheep.

The feed lime excavated at the Ouplaas mine of Anglo-Alpha (Ltd) in north-western Cape has a greyish, cement-like colour. This colour is probably due to a very high level of manganese (Mn) in the lime, up to 5 000 mg/kg. Since this is not a well-recognized colour for feed lime, concern was expressed about the safety of the product to livestock. In fact, cases of poor health and deaths among livestock which consumed rations containing the Ouplaas lime, were attributed to the lime. To ascertain whether the Ouplaas source of lime is indeed a safe feed ingredient, sheep were fed a finishing diet containing either the Ouplaas lime or a widely used feed lime from Umzinkulu, known as Kulu lime.

Thirty-two weaned SA Mutton Merino lambs, with an average mass of 27.4 kg, were grouped into blocks of four according to body mass and sex. One sheep per block was allocated at random to one of the following four treatments: 1% Kulu lime; 4% Kulu lime; 1% Ouplaas lime; 4% Ouplaas lime, included in a commercial sheep finishing ration with no calcium (Ca) added to the basic diet. The sheep were housed individually and fed *ad libitum*. Feed intake and mass gains were recorded over a period of 69 days. Blood was collected on four occasions (before fresh feed was supplied in the morning) during the trial to determine mineral concentrations in plasma, the packed cell volume, haemoglobin levels in whole blood and the concentrations of plasma enzyme, aspartate transaminase (AST: EC 2.6.1.1), alkaline phosphatase (ALP: EC 3.1.3.1), aldolase (ALS: EC 4.1.2.13) and creatine kinase (CK: EC 2.7.3.2). Any sign of abnormal health was recorded. On day 69, when the lambs were slaughtered, the average mass was 43 kg. Carcass, liver and kidney masses were recorded. The concentrations of Mn, copper (Cu) and zinc (Zn) in the livers and kidney cortices were determined. These tissues, preserved in formosaline, were histologically evaluated (Dr W.S. Botha, Consultant Veterinary Pathologist, Pretoria). The plasma enzyme levels were determined with the use of Boehringer Mannheim standard kits (Boehringer Mannheim GmbH Diagnostics, West Germany). The third rib was collected for measurement of bone mineralization (Sykes *et al.*, 1973). Minerals in the feed (Tables 1 and 2), in faeces grab samples collected over a 10-day period [Ca and phosphorus (P)], in plasma [Ca, inorganic phosphate, magnesium (Mg), sodium (Na), Cu and Zn], and in livers and kidney cortices (Mn, Cu and Zn) were determined using atomic absorption spectrophotometry, except for P and inorganic phosphate, where methods published by AOAC (1985) were used. The accuracy of mineral analyses was controlled with National Bureau of Standard's reference samples (NBS, Washington, DC). Data were subjected to analyses of variance, using the Minitab Statistical Software (Minitab Inc. State College, PA 16801, USA).

The Ouplaas lime contained about 5 000 mg/kg Mn, as reported by the manufacturer, i.e. almost 100 times the concentration of Mn in the Kulu lime. The Kulu lime contained much higher levels of Al (10 times) and Fe (twice) than the Ouplaas lime. The other minerals were present at more or less the same concentrations in the two lime sources (Table 1).

The mineral concentrations of the final mixtures were approximately the same, except for Ca, Mn, Fe and Al, as presented in Table 2. The 4% Ouplaas diet contained 331 mg Mn/kg as compared to less than 200 mg Mn/kg in the other diets. The 331 mg Mn/kg is well below 1 000 mg/kg, which is the suggested maximum safe level of Mn for farm animals (NRC, 1980). The concentrations of Ca in the 4% lime diets were over 1.5%, which is well above the requirements of sheep of 0.4 to 0.5% (NRC, 1985), but not at a toxic level (NRC, 1980). High Ca intakes are reported to be antagonistic to the metabolism of Mn in the body (Miller, 1979). At a very high Mn intake, Mn may interfere with Fe absorption, especially if Fe is at a deficient level (Underwood, 1979), a situation which did not exist in the present trial. The high concentrations of Al and Fe in the Kulu lime were diluted in the diets to levels that should pose no risk of toxicity to the animal (NRC, 1980; Black *et al.*, 1985).

No differences in body mass gains (average of 245 ± 38 g/d) were observed between treatments. The total feed intakes of the two 4% groups were higher ($P < 0.05$) than those of the 1% lime groups (Table 3), though efficiency of feed utilization (average 5.7 ± 0.6) did not differ between treatments. No health problem related to the treatments was observed during the trial. The sheep in the two Kulu treatments had heavier livers ($P < 0.05$) than those which received the Ouplaas lime. This was also reflected in the ratios of liver

Table 1 Mineral composition of the pure lime sources (dry basis)

Lime sources	Mg (%)	Na (%)	K (%)	Fe (mg/kg)	Mn (mg/kg)	Al (mg/kg)	Zn (mg/kg)	Cu (mg/kg)
Kulu	0.84	0.07	0.04	2620	45	3331	40	6.5
Ouplaas	0.54	0.07	0.02	1604	4959	356	47	7.3

Table 2 Calcium, manganese, iron and aluminium concentrations of experimental diets (dry basis)

Experimental diet	Calcium (%)	Manganese (mg/kg)	Iron (mg/kg)	Aluminium (mg/kg)
1% Kulu	0.65	121	377	122
4% Kulu	1.73	121	481	310
1% Ouplaas	0.70	174	323	83
4% Ouplaas	1.84	331	387	133

Table 3 Parameters showing significant differences or trends when different sources and levels of lime were fed to sheep

Experimental diet	Total feed intake[1] (kg)	Liver		Faecal concentrations (dry basis)	
		Mass wet (g)	As % body mass	Calcium (%)	Phosphorus (%)
1% Kulu	89.8^{a} ± 3.0	736^{a} ± 36	1.69^{a} ± 0.05	1.7^{a} ± 0.13	0.72^{a} ± 0.02
4% Kulu	97.9^{b} ± 3.2	725^{a} ± 39	1.63^{a} ± 0.06	4.7^{c} ± 0.14	0.60^{c} ± 0.02
1% Ouplaas	88.4^{a} ± 3.0	634^{b} ± 36	1.46^{b} ± 0.05	1.7^{a} ± 0.13	0.78^{a} ± 0.02
4% Ouplaas	93.2^{b} ± 3.2	648^{b} ± 39	1.53^{b} ± 0.06	5.3^{c} ± 0.14	0.57^{c} ± 0.02

a — b Values within columns with different superscripts differ significantly at $P < 0.05$.
a — c Values within columns with different superscripts differ significantly at $P < 0.01$.
[1] On 'as fed' basis; recorded over a period of 69 days.

mass to body and carcass masses (Table 3), although these values were within the normal range for sheep (Van Ryssen, 1981). No obvious explanation can be given for this difference.

The concentrations of Mn in the livers of the two Ouplaas groups were higher ($P < 0.05$) than those found in the livers of the Kulu groups. When expressed as liver Mn content, no differences were observed between the groups (Table 4).

Table 4 Manganese in the livers and kidneys of the sheep which received the different sources of lime

Experimental diet	Liver		Kidney cortex
	Mn concentration (mg/kg DM)	Mn content (g)	Mn concentration (mg/kg DM)
1% Kulu	13.8 ± 0.89^{a}	3.10 ± 0.26	6.7 ± 0.28
4% Kulu	14.4 ± 0.95^{a}	3.21 ± 0.28	7.1 ± 0.30
1% Ouplaas	16.9 ± 0.87^{b}	3.38 ± 0.26	7.9 ± 0.28
4% Ouplaas	17.6 ± 0.95^{b}	3.52 ± 0.28	6.7 ± 0.30

a — b Values with different superscripts differ significantly at $P < 0.05$.

These Mn concentrations corresponded well with those in the literature, e.g. at a dietary level of 500 mg Mn/kg, Black *et al.* (1985) measured 19.5 mg Mn/kg in the livers and 6.4 mg Mn/kg in the kidneys of sheep, while Ivan & Hidiroglou (1980) reported a level of 13 mg Mn/kg in the livers and 7 mg Mn/kg in the kidneys of sheep which consumed a diet containing 300 mg Mn/kg.

None of the following measurements showed significant differences between treatments: liver Cu (334 ± 79 mg/kg DM) and Zn (113.5 ± 23.7 mg/kg DM), kidney cortex Cu (21.5 ± 2.8 mg/kg DM) and Zn (126.7 ± 24.5 mg/kg DM), mineral concentration in plasma (Ca: 9.2 ± 0.7 mg/100 ml; P: 6.8 ± 1.2 mg/100 ml; Mg: 27.7 ± 1.7 mg/l; Na: 3.63 g/l; Cu: 0.77 ± 0.13 mg/l and Zn: 1.26 ± 0.17 mg/l), haemoglobin levels (10.8 ± 0.8 g/100 ml) and packed cell volume in blood (32.9 ± 2.3%). The histopathological evaluation of the livers and kidneys did not reveal any abnormalities. Plasma enzyme concentrations did not differ between treatments (ALP: 515 ± 142 U/l; AST: 72 ± 18.8 U/l; ALS: 8.3 ± 2.1 U/l and CK: 92 ± 50 U/l), indicating that a catabolism of body tissue did not take place in any of the sheep. The bones of the 4% lime groups contained more ($P < 0.01$) ash than those of the 1% lime treatments (Table 5). This was evident also from the bone ash to bone volume ratio and the ash to organic matter ratio. This may suggest that the two sources of lime supplied Ca with an equal efficiency for bone formation.

It can be concluded that, at realistic inclusion rates of lime in sheep diets, the lime will constitute such a small proportion of the total diet that only lime containing very toxic substances would affect the animal. It seems unlikely that Mn, which is a very 'safe' mineral (Miles *et al.*, 1986), could present a risk at the inclusion rates demonstrated in the present investigation.

Table 5 Effect of different levels of lime on measurements of the third rib

Experimental diet	Ash (%)	Ratios		
		Ash : Volume	Organic matter : Volume	Ash : Organic matter
1% Kulu	60.2 ± 0.5^{a}	0.64 ± 0.02^{a}	0.43 ± 0.02	1.52 ± 0.03^{a}
4% Kulu	62.9 ± 0.5^{b}	0.76 ± 0.03^{b}	0.46 ± 0.02	1.70 ± 0.03^{b}
1% Ouplaas	61.1 ± 0.5^{a}	0.64 ± 0.02^{a}	0.41 ± 0.02	1.58 ± 0.03^{a}
4% Ouplaas	63.9 ± 0.5^{b}	0.71 ± 0.03^{b}	0.40 ± 0.02	1.77 ± 0.03^{b}

a — b Values within columns with different superscripts differ significantly at $P < 0.01$.

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