S. Afr. J. Anim. Sci. 10, 165 - 173 (1980)

IN VIVO ESTIMATION OF BODY COMPOSITION IN CATTLE WITH TRITIUM AND UREA DILUTION. I. ACCURACY OF PREDICTION EQUATIONS FOR THE WHOLE BODY

Receipt of MS 01-11-1979

H. H. Meissner, J.H. van Staden and Elma Pretorius
Animal and Dairy Science Research Institue, Private Bag X2, Irene

(Key words: *Predicting body composition, whole body, cattle)*
(Sleutelwoorde: *Voorspelling van liggaamsamestelling, heel-liggaam, beeste)*

OPSOMMING: DIE *IN VIVO* BERAMING VAN LIGGAAMSAMESTELLING VAN BEESTE MET BEHULP VAN TRITIUM- EN UREUMVERDUNNING. I. DIE AKKURAATHEID VAN VOORSPELLINGSVERGELYKINGS VIR DIE HELE LIGGAAM

Vier Afrikaner, 3 Afrikaner-Frieskruis, 4 Bonsmara, 5 Charolais en 4 Hereford bulle in die massagebied 101-772 kg is gebruik om die moontlikhede van die tritium- en ureumverdunningstegniek vir akkurate beraming van liggaamsamestelling te toets. Omtrent 1,1 - 1,4 g ureum/$W_{kg}^{0,75}$ en 30 - 40 μCi tritium/$W^{0,75}$ is per *vena jugularis* aan elke bul toegedien waarna bloedmonsters met gereelde tussenposes oor die volgende 7 uur bekom is. Vervolgens is die bulle geslag, die regtersy van die karkas is fisies ontleed vir beramings van vleis, vet en been, terwyl die linkersy en die nie-karkasdele volledig opgemaal is vir die bepaling van vog, N, eterekstrak, anorganiese materiaal en verbrandingsenergie.

Die optimum tydstip vir bloedmonstering teneinde leë liggaamsvog te beraam was 10 ± 3,4 min na infusie vir ureum en 5 ± 2,1 min vir tritium, terwyl dit onderskeidelik 18 ± 4,6 en 234 ± 73 min was vir die bepaling van totale liggamsvog. Die samestelling van die eterekstrak-vrye, leë liggaam en die eterkstrakvrye, vogvrye liggaam was onderskeidelik 72,2 ± 2,22% vog, 22,5 ± 2,05% proteïen en 5,40 ± 0,48% anorganiese materiaal en 80,6 ± 1,69% proteïen en 19,4 ± 1,69% anorganiese materiaal wat besonder nou ooreenstem met die syfers van Reid *et al.* (1968).

Lineêre regressieverwantskappe met tritium- of ureumruimte en lewende massa as onafhanklike veranderlikes en die chemiese komponente van die bulliggame is opgestel. Die eterekstrakvrye komponente van die liggaam - vog, proteïen en anorganiese materiaal kon beraam word met 'n koeffisiënt van variasie van 4 - 10% by 'n lewende massa van 400 kg, terwyl die koeffisiënt van variasie vir die beraming van eterekstrak 25 - 30% was. Laasgenoemde waarde is duidelik te groot om met 'n enkel meting uitspraak oor liggaam-samestelling binne of tussen rasse te maak. Derhalwe sal die tegniek herhaaldelik toegepas moet word.

SUMMARY:

Four Afrikaner, 3 Afrikaner x Friesian, 4 Bonsmara, 5 Charolais and 4 Hereford bulls within the mass range 101 - 772 kg were used to evaluate the tritium and urea dilution techniques for accurate prediction of body composition. Approximately 1,1 - 1,4 g urea/$W_{kg}^{0,75}$ and 30 - 40 μCi tritium/$W_{kg}^{0,75}$ were infused per *vena jugularis* whereafter blood samples were collected at regular intervals until 7 hours post-infusion, Following sampling of blood, the animals were slaughtered. The right sides of the carcasses were physically analysed for muscle, bone and fat and the left sides plus the non-carcass components minced *in toto* and analysed for water, N, ether extract, in-organic material and energy of combustion.

The optimum time to sample blood in order to predict empty body water was 10 ± 3,4 min post-infusion for urea and 5 ± 2,1 min for tritium, while it was 18 ± 4,6 and 234 ± 73 min respectively, for accurate prediction of total body water. The composition of the ether extract-free, empty body was 72,2 ± 2,22% water, 22,5 ± 2,05% protein and 5,40 ± 0,48% inorganic material while that of the ether extract-free dry body was 80,6 ± 1,69% protein and 19,4 ± 1,69% inorganic material. These values correspond very closely with the values of Reid *et al.* (1968).

Linear regression equations with tritium or urea space and live mass as independent variables and the chemical components of the body were calculated. The ether extract-free components of the body - water, protein and inorganic material could be predicted with a co-efficient of variation of 4 - 10% at a live mass of 400 kg, while the coefficient of variation for ether extract was 25 - 30%. The latter is clearly of such magnitude that body composition differences between bulls within or between breeds would not be able to quanfied unless measurements can be made repeatedly.

In recent years various substances have been tested to facilitate the estimation of body composition in the live animal. Some of the substances earlier used such as AP, NAAP and creatinine proved to be insufficiently accurate (Reid, Bensadoun, Paladines & van Niekerk, 1963). Others were shown to be more reliable in predicting body composition than either body mass or empty body mass. Of the radio-active materials, tritium is used extensively because it appears to be reasonably accurate in most situations (Robelin, 1973) and because it is relatively easy to administer and to detect. Potassium - 40 has also become popular (Clark, Hedrick & Thompson, 1976; Belyea, Frost, Martz, Clark & Forkner, 1978). However, since radio-active materials can be hazardous with regard to disposal of urine, faeces and carcasses, researchers also resort to non-radio-active materials for routine use. Of these deuterium (Foot & Greenhalgh, 1970; Robelin, 1977), urea (Preston & Kock, 1973; Meissner, 1976; Kock & Preston, 1979) and ethanol (Leoppky, Myhre, Venters & Luft, 1977), among others, showed a level of accuracy comparable to that obtained for the radio-active substances.

For various purposes a number of prediction equations based on tritiated water space have been developed to estimate body composition in farm animals. Among ruminants most studies have been conducted with sheep (Panaretto, 1968; Reardon, 1969; Searle, 1970; Hofmeyr, Olivier, Kroon & van Rensburg, 1971; Smith & Sykes, 1974; Meissner & Bieler, 1975) while the effort in cattle has been limited to calculations of body-water space (Aschbacher, Kamal & Cragle, 1965; Carnegie & Tulloh, 1968). With regard to urea space Preston & Kock (1973) and Kock & Preston (1979) published prediction equations to estimate body composition, but the reliability of their equations could have been influenced by their using specific gravity to determine fat which is less accurate than chemical analysis of the minced body or carcass, or their analysis of a specific cut instead of the whole carcass whereby a further indirect estimate is required. Using sheep Meissner (1976) showed the urea dilution technique to be somewhat less reliable than tritium dilution, but he suggested that due to low cost it could be useful for routine calculations of body composition in cattle.

In view of the apparent lack of extensive prediction functions for cattle a slaughter study was conducted with beef cattle to establish equations based on tritiated water and urea space to predict body composition in the live animal and the carcass, and to evaluate their accuracy in comparison to those derived from ^{40}K (Clark *et al*, 1976; Belyea *et al*, 1978). From the latter studies the uniquely comprehensive prediction equations support the reliability of the ^{40}K method which can be used by laboratories having access to a Whole Body Counter.

In this paper prediction equations to estimate the composition of the whole body are presented. In subsequent papers results are presented for the "chemically" analysed and the physically dissected carcass, as well as for the non-carcass components.

Procedure

1. Animals and management

Four Afrikaner, 3 Afrikaner x Friesian, 4 Bonsmara, 5 Charolais and 4 Hereford bulls were used. They were housed indoors.

Within each breed one animal was selected at random and placed on a medium quality roughage diet consisting primarily of *Eragrostis* hay. A further Bonsmara bull was added to this group, while the remaining 14 bulls were fed a cubed commercial diet having a crude protein content of 15% (DM basis) and a digestible energy content of 69% at *ad libitum* intake. To this was added 1 - 2 kg *Eragrostis* hay per head per day depending on body mass. Both diets were consumed *ad libitum* and water was freely available.

Slaughter masses ranged from 101 - 772 kg and the bulls within each diet were allocated to these mass categories at random.

The animals were not fasted before administration of the urea and tritium solutions, but feed and and water were withheld during distribution of the test substances through the body.

2. Infusion and blood sampling

Urea and tritium in a 0,9% NaCl carrier solution were infused simultaneously (intravenously) by means of an indwelling catheter and a 12 gauge needle. The required amount of solution, to be infused, was carefully weighed into 20 and 50 ml sterilized disposable syringes which were attached to the catheter by a luer-lock arrangement. Mild force was necessary to introduce the substances into the bloodstream within 2,5 minutes.

The urea solution contained 50% urea while the tritium solution averaged 200 μCi/g. Between 1,1 - 1,4 g/$W_{kg}^{0,75}$ urea and 30 - 40 μCi/$W_{kg}^{0,75}$ tritium were infused, the actual amounts being determined accurately.

Jugular blood samples were taken prior to and at 5, 10, 15, 20, 30, 60, 120, 240, 360, and 420 min following administration. Those scheduled for tritium analysis were stored at 4°C while the others were centrifuged and the plasma kept at -20°C until they could be analysed for urea - N.

3. Sample analysis and water space calculation

Plasma samples were analysed for urea -N according to the automated method of Marsh, Fingerhut & Miller (1965)

using a Model I Technicon Auto Analyzer. Tritiated water (TOH) was recovered quantitatively from the blood samples by vacuum sublimation. The specific activity of the TOH was measured in a Packard Liquid scintillation counter using 1,0 g duplicate aliquots of radio-active water in 10 ml scintillation liquid as described by Meissner & Bieler (1975).

Apparent urea or TOH space was calculated from the ratio of urea or tritium infused to the concentration at equilibrium, or at various other stages prior to equilibrium, after correction for the pre-injection values. No correction was made for losses of urea or tritium that might have occurred during blood sampling.

4. Slaughter procedure

The slaughter procedure employed has been described by Naudé (1974). The blood was collected and weighed during the killing process. The body was flayed and the digesta removed from the alimentary tract, whereafter the water content of the digesta was obtained by desiccation.

For chemical analysis the following non-carcass components were pooled: head, trotters, digestive tract, viscera and blood, while the hide was kept separate. The carcass was split into halves, the left side being assigned for chemical analysis and the right side for physical dissection and determination of muscle, bone and various fat stores. It was assumed that each half of the carcass would be identical in composition.

The hide, other non-carcass components and the left side of the carcass were frozen before being minced separately *in toto* in a Wolking carcass grinder fitted with two die plates with 12 and 5 mm holes respectively (Hofmeyr, 1972). Mincing was carried out 5 to 6 times to ensure a homogenous product before large samples (± 500 g) were taken for analyses for DM, N, ether extract, inorganic matter and energy of combusion (A.O.A.C., 1970). Mass losses during mincing were assumed to be moisture and the results were corrected for this loss. The right sides of the carcasses were chilled for ± 18h at 2 - 4°C.

Adopting the procedures described by Naudé (1974) the tissues of the carcass obtained by physical dissection were bone, subcutaneous and kidney fat. "Meat" comprised muscle and intra as well as intermuscular fat. In addition, the amounts of bone, subcutaneous fat and meat in the prime rib cut were also identified. The amount of muscle in the carcass and prime rib cut was calculated by adding together the masses of protein, water and inorganic matter as obtained by chemical analyses of representative samples. The total amount of fat in the carcass or prime rib cut is the sum of the ether extract in the subcutaneous and intermuscular fat and the muscle.

5. Statistical analysis

Least square analyses were used to establish prediction equations for the components of body composition. One-way analysis of covariance (Snedecor, 1956) was used to test for differences between breeds and diets. The reliability of prediction equations was evaluated by the square of the correlation coefficient, the Sy.x and the 95% confidence limits for prediction at the extremes of experimentation (see range column, Table 2). The latter indicates the probable boundaries within which 95% of observations in conceptual further experiments or observations in an extrapolated experimental range would fall.

Results and Discussion

1. Optimum time for blood sampling

Using a time-equilibration curve for infused-urea and tritium as illustrated by Meissner (1976), the most suitable point in time to sample blood following administration can be calculated. By extrapolating the linear straight portion of the curve to zero-time the concentration of urea or the activity of tritium can be estimated, if complete equilibrium is immediately achieved. Urea or TOH space, calculated at the point of equilibrium, estimates total body water (TBW) if in the case of TOH space provision is made for exchange with labile hydrogen atoms in various compounds in body tissues and losses occurring through evaporation and urine (Carnegie & Tulloh, 1968). These time values together with the optimum point in time for blood sampling when urea or TOH space corresponded with empty body water space (EBW), that is TBW minus water in the gut, are shown in Table 1.

Table 1

Time-optimum for blood sampling to calculate urea and TOH space corresponding respectively to TBW and EBW

	Time-optimum for blood sampling (min.)	
	TBW	EBW
Urea	18 ± 4,6	10 ± 3,4
Tritium	234 ± 73	5 ± 2,1

The optimum time for sampling blood at equilibrium (TBW) corresponds with that obtained by Meissner (1976). The time-optimum for blood sampling to estimate EBW differs however, because the infusion volume and the method of administration were somewhat different in the two experiments. This shows that the procedures adopted and the volumes infused should be standardized between experiments if EBW is to be

Table 2

Means and ranges in body mass and composition

	Mean	Range
Body mass (kg)	384,7	101 - 772
TBW (kg)	248,1	73,5 - 474
EBW (kg)	206,1	61,6 - 407
Protein (N x 6,25) (kg)	68,56	15,9 - 154
Inorganic matter (kg)	15,89	4,01 - 32,5
Ether extract (kg)	47,08	4,57 - 164
Energy of combustion (MJ)	3465	556 - 8954

estimated from blood sampling shortly after administration of urea or tritium. The time-optimum to estimate EBW from urea space here was not significantly different from the 12 minutes post administration found by Kock & Preston (1979).

2. Chemical composition of the beef body

Means and ranges of the constituents of the body are shown in Table 2.

The data in Table 3 illustrates the agreement in composition of the ether extract (EE)- free, empty body and the EE-free, dry body between the results of Reid, Bensadoun, Bull, Burton, Gleeson, Han, Yoo, Johnson, McManus, Paladines, Stroud, Tyrell, Van Niekerk & Wellington (1968) and the present. The variation in constituents of the EE-free, empty body is higher than the variation in the EE-free, dry body, because the water-protein relationship is age and body-mass dependent (Reid *et al.*, 1968). For example, the correlation coefficient between the EE-free, empty body and percentage *EBW* was -0,92 in the present experiment.

The composition of the EE-free, empty body and the EE-free, dry body was not significantly influenced by breed of bull or diet. This also applied to the relationship between the concentration of water and EE which is in agreement with the results of Reid *et al.* (1968).

3. Relationship between urea or TOH space and water

The relationships considered were:

3.1 Urea space calculated from blood sampling at 10 minutes post-Infusion ($Urea_{10}$) in relation to EBW.

3.2 TOH space calculated from blood sampling at 6 hours post-infusion (at equilibrium) (TOH_{360}) in relation to TBW and EBW.

3.3 TOH space calculated from blood sampling at 5 minutes post-infusion (TOH_5) in relation to EBW.

These relationships were not significantly influenced by breed or diet although dietary effects in the contents of the reticulorumen were noticable. The data were therefore pooled, and common regression equations calculated. In addition to TOH or urea space, body mass was introduced as second independent variable in some regression analyses to compare the reliability of the multiple linear equation to the simple linear one in predicting TBW and EBW. Where the intercept on the Y-axis was not significantly different from zero, it was assumed that the regression line should pass through the origin and the slope/regression coefficients were therefore computed from the uncorrected sum of squares. The relationships are shown in Table 4.

Table 3

Composition of the ether extract-fee, empty body and the ether extract-free, dry body

	EBW (%)	Protein (%)	Inorganic matter (%)
a. *Ether extract-free, empty body*			
Present experiment	72,2 ± 2,22 (3,1)*	22,5 ± 2,05 (9,1)	5,40 ± 0,48 (9,9)
Reid *et al* (1968)	72,9 ± 2,01 (2,8)	21,6 ± 1,53 (7,1)	5,34 ± 0,95 (17,8)
b. *Ether extract-free, dry body*			
Present experiment	-	80,6 ± 1,69 (2,1)	19,4 ± 1,69 (8,7)
Reid *et al* (1968)	-	80,3 ± 1,69 (2,1)	19,7 ± 1,69 (8,6)

* Coefficient of variation.

Table 4

Prediction equations for TBW and EBW in kg

	Prediction equation	r^2 or R^2	Sy. x	95% confidence limits
TBW	= 0,861 TOH_{360}	–	12,4	± 26,6
	= 0,687 TOH_{360} + 0,127 Mass	–	12,6	± 27,1
EBW	= 1,017 $Urea_{10}$	–	16,5	± 35,6
	= 0,463 $Urea_{10}$ + 0,286 Mass	–	8,51	± 18,4
	= 0,719 TOH_{360}	–	13,8	± 29,6
	= 0,408 TOH_{360} + 0,228 Mass	–	12,5	± 26,9
	= 0,991 TOH_5	–	8,70	± 18,7
	= 0,803 TOH_5 + 0,100 Mass	–	8,42	± 18,1
	= 0,487 Mass + 18,9	0,979	14,4	± 31,0

The reciprocal of the slope of the regression equation between TOH_{360} and TBW is 1,16 which is about the same as the one of 1,15 calculated by Carnegie & Tulloh (1968) when they used TOH space at equilibrium as dependent variable. This confirms that if ruminants are not fasted beforehand, TBW is overestimated by 15 - 16%.

Carnegie & Tulloh (1968) used TBW as independent variable on the assumption that it is a more accurate estimate of the water content of animals. This is also recognized here as the more correct procedure. However, by adopting that procedure it is somewhat inconvenient to calculate the error involved in the prediction of TBW, which in actual fact one is interested in. Therefore, it was decided to retain TOH space as independent variable as in earlier publications even though the fit of regression equations may have been less accurate.

The error of prediction of TBW from TOH_{360} space in the present case is about twice that obtained by Carnegie & Tulloh (1968). The Sy.x in their publication appears to be about 6 kg. It would appear that the contents of the gut were more variable in the present experiment since the relationships calculated for the concentrate and roughage diets were pooled. Whereas EBW is predicted with a Sy.x of 8,7 kg from TOH_5 space, which compares favourably with the 9kg of Clark *et al.* (1976) if correctly interpreted, the Sy.x increases to 12,7 kg if TBW is predicted, which shows that the error of prediction is increased by about 50% if the gut contents are taken into account.

From Table 4 it can be seen that the error of prediction of EBW is higher when $Urea_{10}$ is used in comparison to either measures of TOH space. This is in accordance with the results of Meissner (1976). If body mass is introduced

Table 5

Prediction equations for protein in kg

	Prediction Equation	r^2 or R^2	Sy.x	95% confidence limits
Protein	= 0,421 $Urea_{10}$ – 16,9	0,919	11,7	± 25,4
	= –0,067 $Urea_{10}$ + 0,216 Mass	–	5,61	± 12,2
	= 0,298 TOH_{360} – 17,7	0,964	7,61	± 16,3
	= –0,061 TOH_{360} + 0,226 Mass	–	7,19	± 15,5
	= 0,393 TOH_5 – 13,1	0,976	6,22	± 13,4
	= 0,159 TOH_5 + 0,117 Mass – 9,72	0,985	5,28	± 11,5
	= 0,195 Mass – 6,66	0,981	5,59	± 12,1

Table 6

Prediction equations for inorganic matter in kg

	Prediction equation	r^2 or R^2	Sy.x	95% confidence limits
Inorganic matter	= 0,079 $Urea_{10}$	–	1,80	± 3,89
	= 0,021 $Urea_{10}$ + 0,030 Mass	–	1,21	± 2,65
	= 0,063 TOH_{360} – 2,50	0,947	1,98	± 4,32
	= 0,021 TOH_{360} + 0,026 Mass	–	1,93	± 4,18
	= 0,078 TOH_5	–	1,74	± 3,74
	= 0,050 TOH_5 + 0,015 Mass	–	1,81	± 3,92
	= 0,041 Mass	–	1,98	± 4,27

as second variable the error is decreased, considerably so in the case of the urea space relationship. The order of decrease is between 4 and 50% showing that it can be of value to include body mass as second variable. It is interesting to note that body mass *per se* is a reasonably accurate predictor of EBW.

The 95% confidence limits for predicting TBW or EBW at the extremes suggest that a "casual observation" (Carnegie & Tulloh, 1968) at the lower end of the scale – a calf for example – might be unsatisfactory. This indeed, would be true for all composition components (Tables 5 to 7).

4. Relationship between urea or TOH space and protein

The same independent variables as before were used to predict protein and the other constituents. The relationships for protein are shown in Table 5.

The prediction of protein from either urea or TOH space was less accurate than prediction from body mass which is in accordance with the report of Clark *et al.* (1976) using ^{40}K to predict empty body nitrogen %. Although the Sy. x was reduced, considerably so in the case of $Urea_{10}$ when body mass was introduced as second variable to urea or TOH space, it is evident that nothing is to be gained in accuracy by using water space measurement. Body mass as independent variable would be sufficient if the same sex is used. The body mass-protein relationship is probably influenced by sex (Meissner, Roux & Hofmeyr, 1975; Meissner, De la Rey, Gerhard & Van der Westhuizen, 1976).

5. Relationship between urea or TOH space and inorganic matter

The relationships for inorganic matter are shown in Table 6.

Table 7

Prediction equations for ether extract in kg

	Prediction equation	r^2 or R^2	Sy.x	95% confidence limits
Ether extract	= 0,264 $Urea_{10}$	–	30,7	± 66,2
	= –0,627 $Urea_{10}$ + 0,460 Mass	–	14,2	± 30,7
	= 0,270 TOH_{360} – 30,5	0,677	25,2	± 54,3
	= –0,657 TOH_{360} + 0,616 Mass	–	14,6	± 31,4
	= 0,252 TOH_5	–	27,4	± 58,8
	= –1,074 TOH_5 + 0,706 Mass	–	12,9	± 27,8
	= 0,188 Mass – 24,8	0,777	20,9	± 45,0

Table 8

Mean absolute error and standard deviation of the calculated amount of ether extract (kg)

Method of calculation	Mean error and S. D.
Directly from TOH_5 and Mass	9,87 ± 8,26
Indirectly via EBW	9,64 ± 8,63
Indirectly via subtraction	11,9 ± 7,67
Directly via the log equation	8,94 ± 11,1

The prediction of inorganic matter from urea or TOH space proved to be at least as accurate as prediction from body mass. When urea or TOH space and body mass were both used as independent variables the accuracy improved even further (between 3 and 33%).

6. Relationship between urea or TOH space and ether extract (EE)

The relevant relationships are shown in Table 7.

It is evident that without body mass as second independent variable the prediction of the amount of EE from urea or TOH space was extremely unreliable. Body mass as sole variable was substantially better, but still predicted inaccurately. This of course, is due to the fact that the EE-body mass relationship is breed dependent.

Urea or TOH space together with body mass as independent variables predicted the amount of EE with a Sy.x of 12,9 – 14,6 kg which is somewhat higher than the figure of about 11,5 kg (if interpreted correctly) reported by Clark *et al.* (1976) when they predicted the amount of EE from ^{40}K and live mass as independent variables. Bearing in mind that their experimental animals were a homogenous group of Hereford steers and that they fasted the steers beforehand, one would have expected a smaller error.

If the Sy.x is calculated in terms of percentage error relative to the mean amount of EE in the experiment (see Table 2), it becomes 27,4 – 31,0% which clearly is quite unsatisfactory. Compare this error with the corresponding ones for TBW of about 5,0%, EBW of about 4,1%, protein of about 8,0% and inorganic matter of about 10,5%.

Due to the smaller error of the EE-free components the possibility that the error of estimate of EE might be reduced if it is calculated indirectly was investigated. Two procedures were followed: In the first instance EBW was calculated from TOH_5 and body mass as in Table 4. (Only TOH_5 was considered since it was assumed that the same principles would apply in the case of TOH_{360} and $Urea_{10}$). The amount of EE was then calculated from EBW as derived from the first equation and body mass. In the second instance 2 equations were calculated, one between empty body mass (i.e. without the contents of the gut) and body mass and one between EE-free empty body mass and TOH_5. The amount of EE was then considered as the difference between the empty body and the EE-free empty body. It was considered worthwhile to pursue a further possibility. This was that the relationship between the amount of EE, TOH_5 and body mass is linear only in the log scale and therefore theoretically the amount of EE should be predicted with highest accuracy when calculated from the log relationship. The different methods were compared with regard to the mean absolute error of calculated amount of EE relative to chemically analysed EE as shown in Table 8.

The procedure for calculating the amount of EE via EBW was of similar accuracy to the direct method in the ordinary scale. The subtraction procedure proved to be less reliable. The mean absolute error when the log procedure was used was about 10% less than the direct method in the ordinary scale, but the S.D. was substantially increased. This was mainly due to the fact that the log equation calculated the amount of EE at the upper end of the scale (high ether extract contents) in a biased manner. Overall, it is clear that nothing is to be gained in accuracy by the proposed approaches.

The error of estimates of the amount of EE (27,4 – 31,0%) is greater than the differences in EE content between most beef breeds (Naudé, 1974; Meissner, unpublished) which means that the method of measuring water space with urea or tritium dilution is unsuitable for comparing breeds unless one can resort to repeated measurement within each animal (Meissner & Roux, 1979).

7. Relationship between urea or TOH space and energy of combustion

The prediction equations for energy of combusion are given in Table 9.

The inclusion of body mass as second independent variable to urea or TOH space reduced the Sy.x about 50%. Nevertheless, the Sy.x remained relatively high compared to the error of the EE-free components, because of the influence of the EE error. The percentage error relative to the mean energy of combustion content was about 14 – 15%.

The Sy.x for prediction of energy of combusion reported by Clark *et al.* (1976) appears to be about 414 MJ. The reasons why this figure is expected to be lower than the present have been discussed previously.

Table 9

Prediction equations for energy of combustion in MJ

	Prediction equation	r^2 or R^2	Sy. x	95% confidence limits
Energy of combusion	= 18,6 $Urea_{10}$*	–	1411	± 3042
	= –25,9 $Urea_{10}$ + 23,0 Mass	–	515	± 1115
	= 17,5 TOH_{360} – 1589	0,829	1081	± 2327
	= –27,2 TOH_{360} + 29,5 Mass	–	536	± 1154
	= 22,8 TOH_5 – 1263	0,821	1105	± 2379
	= –41,8 TOH_5 + 31,8 Mass	–	507	± 1092
	= 11,9 Mass – 1110	0,909	790	± 1701

* Urea and TOH space and body mass are in kg

Conclusions

1. The EE-free components of the body – water, protein and inorganic matter – can be estimated with a mean absolute error of about 4 – 10% at a live mass of 400 kg.

2. The amount of EE would be estimated with a mean absolute error of about 25 – 30% at 400 kg live mass.

3. Urea space as sole predictor of body composition is slightly less accurate than TOH space. However, the differences disappear when body mass is introduced as second independent variable.

4. More than one measurement of water space and body mass in the same animal would be required to quantify body composition differences between beef animals.

Acknowledgement

The statistical assistance of Dr C.Z. Roux is appreciated.

References

A.O.A.C., 1970. Official Methods of Analysis of the Association of Official Analytical Chemists, 11th ed. Ed. by W. Horwitz. Washington: Ass. of Off. Anal. Chem.

ASCHBACHER, P.W., KAMAL, J.H. & CRAGLE, R.G., 1965. Total body water estimation in dairy cattle using tritiated water. *J. Anim. Sci.* 24, 430.

BELYEA, R.L., FROST, G.R., MARTZ, F.A., CLARK, J.L. & FORKNER, L.G., 1978. Body composition of dairy cattle by Potassium – 40 liquid scintillation detection. *J. Dairy Science* 61, 206.

CARNEGIE, A.B. & TULLOH, N.M., 1968. The *in vivo* determination of body water space in cattle using the tritium dilution technique. *Proc. Aust. Soc. Anim. Prod.* 7, 308.

CLARK, J.L., HEDRICK, H.B. & THOMPSON, G.B., 1976. Determination of body composition of steers by ^{40}K *J. Anim. Sci.* 42, 352.

FOOT, JANET Z & GREENHALGH, J.F.D., 1970. The use of deuterium oxide space to determine the amount of body fat in pregnant Blackface ewes. *Br. J. Nutr.* 24, 815.

HOFMEYR, H.S., 1972. Kwantifisering van faktore wat die brutodoeltreffendheid van energie-omsetting van voer by skape beinvloed. DSc (Agric.) Thesis, Univ. Pretoria, S.A.

HOFMEYR, H.S., OLIVIER, ILZE, KROON, FREDERIKA, E. & VAN RENSBURG, W.J.J., 1971. Mededeling oor verwantskap tussen tritiumruimte en liggaamsamestelling by drie skaaprasse. *S. Afr. Tydskr. Veek.* 1, 13.

KOCK, S.W. & PRESTON, R.L., 1979. Estimation of bovine carcass composition by the urea dilution technique. *J. Anim. Sci.* 48, 319.

LOEPPKY, J.A., MYHRE, L.G., VENTERS, M.D. & LUFT, U.C., 1977. Total body water and lean body mass estimated by ethanol dilution. *J. Appl. Physiol Respirat. Environ. Exercise Physiol* 42, 803.

MARSCH, W.H., FINGERHUT, B. & MILLER, H., 1965. Automated and manual direct methods for the determination of blood urea. *Clin. Chem.* 11, 624.

MEISSNER, H.H., 1976. Urea space versus tritiated water space as an *in vivo* predictor of body water and body fat. *S. Afri. J. Anim. Sci.* 6, 171.

MEISSNER, H.H. & BIELER, E.U., 1975. A note on the validity of using combinations of predictive equations for estimating body composition from tritiated water space. *S. Afr. J. Anim. Sci.* 5, 7.

MEISSNER, H.H., DE LA REY, P.J., GERHARD, KATRINA, E. & VAN DER WESTHUIZEN, ELNA., 1976. Variasie in die liggaamsamestelling van die skaap. *Agroanimalia* 8, 69.

MEISSNER, H.H., & ROUX, C.Z., 1979. Voluntary feed intake, growth, body composition and efficiency in the sheep: Quantification of between – Animal variation. *Agroanimalia* 11, 9.

MEISSNER, H.H., & ROUX, C.Z., & HOFMEYR, H.S., 1975. Voluntary feed intake, growth, body composition and efficiency in the sheep: Breed and sex differences. *Agroanimalia* 7, 105.

NAUDé, R.T., 1974. Intensiewe vleisproduksie uit melkrasbeeste. D.Sc (Agric.) Thesis, Univ. Pretoria, S.A.

PANARETTO, B.A., 1968. Body composition *in vivo*: IX The relation of body composition to the tritiated water spaces of ewes and wethers fastet for short periods. *Aust. J. agric. Res.* 19, 267.

PRESTON, R.L. & KOCK, S.W., 1973. *In vivo* prediction of body composition in cattle from urea space measurements. *Proc. Soc. exp. Biol. and Med.* 143, 1057.

REARDON, T.F., 1969. Relative precision of the tritiated water and slaughter techniques for estimating energy retention in grazing sheep. *Anim. Prod.* 11, 453.

REID, J.T., BENSADOUN, A., BULL, L.S., BURTON, J.H., GLEESON, P.A., HAN, I.K., JOO, Y.D., JOHNSON, D.E., McMANUS, W.R., PALADINES, O.L., STROUD, J.W., TYRELL, H.F., VAN NIEKERK, B.D.H. & WELLINGTON, G.W., 1968. Some peculiarities in the body composition of animals. In: Proc. Symp. Body Composition in Animals and Man. Univ. Missouri, Columbia. Publ. 1598, *Nat. Acad. Sci.*, Washington D.C.

REID, J.T., BENSADOUN, A., PALADINES, O.L. & VAN NIEKERK, B.D.H., 1963. Body water estimations in relation to body composition and indirect calorimetry in ruminants. *Ann. N.Y. Acad. Sci.* 110, 327.

ROBELIN, J., 1973. Estimation de la composition corporelle des animauz a partir des espaces de diffusion de l'eau marquee'. *Ann. Biol. anim. Bioch. Biophys.* 13, 285.

SEARLE, T.W., 1970. Body composition in lambs and young sheep and its prediction *in vivo* from tritiated water space and body weight. *J. agric. Sci. Camb.* 74, 357.

SMITH, B.S.W. & SYKES, A.R., 1974. The effect of route of dosing and method of estimation of tritiated water space on the determination of total body water and the prediction of body fat in sheep. *J. agric. Sci. Camb.* 82, 105.

SNEDECOR, G.W., 1956. Statistical methods. 5th Edition. The Iowa State University Press, Ames, Iowa, U.S.A.