Predicting the liveweight of sheep by using linear body measurements

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ABSTRACT
The relationship between live body weight and some linear body measurements using data on sheep are explored. Predictive models for body weight were then fitted to the data. The optimum model for predicting live body weight of sheep involves the sex of the animal and its index of volume (estimated as the product of the square of the heart girth and the body length) as predictor variables. A weight chart based on this model is constructed for determining liveweight of sheep, given an animal's sex, its heart girth, and body length. The advantage of this chart over the one developed by the Ministry of Food and Agriculture, Ghana, is briefly discussed.

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RÉSUMÉ
BAFFOUR-AWUAH, O., AMPOFO, E. & DODOO, R. : *Prédisant le poids vif de mouton en utilisant les mesures linéaires du corps.* Le rapport entre le poids vif et quelques mesures linéaires du corps en utilisant les données du mouton est exploré. Les modèles prophétiques pour le poids corporel étaient alors fixés sur les données. Le modèle optimum pour la prédiction de poids vif de mouton entraîne le sexe de l'animal et son indice de volume (estimé comme le produit du tour de cœur carré et la longueur du corps) comme des variables prédiseuses. Un graphique de poids basé sur ce modèle est construit pour la détermination de poids vif de mouton étant donné le sexe d' un animal, son tour de cœur et la longueur du corps. L'avantage de ce graphique par rapport à ce qui est développé par le Ministère de l' alimentation et l'agriculture du Ghana est brièvement discuté.

Introduction

An accurate method of determining the liveweight of livestock is a very important aspect of livestock production. Knowledge of animal's liveweight is necessary for determining its food requirement for growth, maintenance and production, and the correct dosage in drug administration, among other things. Also, the size of the adult animal is intimately associated with mature weight and meat yield. Direct determination of liveweight involves the use of the weighing scale. Proper and accurate measurement of body weight is difficult or even impossible under smallholder production systems due to lack of weighing scales. The need to estimate liveweight of animals from simple and easily measurable variables such as linear body measurements becomes evident.

The Ministry of Food and Agriculture, through its Extension Department, has developed a system of determining liveweight of sheep and goats from the heart girth measurement only (Asare, Akofur & Kpor, 1996). But it is felt that other linear body measurements and other variables may be important in determining the liveweight of an animal. Very few studies have been carried out on different linear body measurements of indigenous breeds of cattle, sheep and goats, and their possible use for estimating the animal's liveweight (Ross, 1957; Balig, 1970; Mukherjee, Singh & Mishra, 1986; Singh, Mohanty & Mishra, 1987; Osinowo *et al.,* 1989; Hassan & Ciroma, 1992; Ahunu & Kpesese, 1995).

This study was carried out to establish the relationship between liveweight and some linear body measurements in sheep as a step towards using predictive models to estimate liveweight of sheep.

Materials and methods

Source of data

The data used for this study were collected on a random sample of 173 sheep kept at the Pong-Tamale Livestock Breeding Station comprising Djallonke, Sahelian and their crossbred, and comprising 29 males and 144 females. The sample was taken without any stratification by breed type and sex of sheep.

Pong-Tamale is situated about 32 km north of Tamale in the Northern Region of Ghana. The area has a single rainfall season, which starts from April/May to September/October. The rest of the year is the dry season, which is characterized by the dry harmattan winds. The annual rainfall is over 1000 mm and an average temperature of between 26 and 36 °C with relative humidity ranging from about 20 per cent in the dry season up to about 83 per cent in the rainy season.

The animals were kept and managed under a semi-intensive system. The flocks were released during the day onto paddocks planted with pigeon pea, stylosanthes and buffel grass. The sheep were watered regularly and given salt lick and supplementary feed comprising cottonseed, cowpea/groundnut haulms, and cassava peels. Measurements were restricted to adult animals not weighing less than 20 kg. After determining the body liveweight on a weighing scale, each animal was placed on all four legs on an even surface, and the following linear body measurements were taken with the tailor's measuring tape:

1. Body length (BDL): the distance from the external occipital protuberance to the base of the tail.
2. Height-at-withers (HWI): the distance from the ground level to the withers.
3. Heart girth (HGR): the circumference of the chest region of the body.
4. Width-at-hip (WHP): the width of the thigh at the hip of the hind leg.
5. Width-at-shoulders (WSD): the distance from the beginning of the shoulder to the withers.
6. Head length (HDL): the distance from the beginning of the upper lip to the external occipital protuberance.
7. Rump length (RUL): the distance from the ground level to the hindback where the tail begins.
8. Tail length (TAL): the distance from the base to the end of the tail.

Statistical analysis

A multiple regression analysis was carried out to describe the relationship between the independent variables consisting of a set of linear body measurements, sex and breed type of sheep, on the one hand, and the liveweight as the response variable, on the other hand. Many methods have been suggested for developing the optimum model involving the appropriate variables (Draper & Smith, 1981). In selecting the appropriate variables for the predictive model, the "All Possible Selection" procedure was adopted. This involved computing all possible and the best subset regression equations. Each equation was then assessed by its coefficient of determination, R^2, and the Mallow's constant, Cp, based on the number of variables used for the prediction. The use of other information such as knowledge of the characteristics of the predictor variables, and the cost of obtaining the information was also considered.

A crucial step in constructing a multiple regression model is to determine those variables that contribute much to the response variable with the elimination of 'unimportant' variables. In all, there were eight body linear measurements with sex and breed type, which were considered as dummy variables. The "All Possible Selection" method gave the optimum number of independent variables and their combination in regression equations for predicting the dependent variable, which is liveweight of an animal.

Results and discussion

Table 1 summarizes the average measurements for all the variables studied. On average, males were heavier (33 kg) than females (29 kg), but females had slightly longer bodies (94 cm) than males (93 cm). This is reflected in other measures as head length (27 cm vs. 26 cm), rump length (71 cm vs. 70 cm), and tail length (33 cm vs. 31 cm)

TABLE 1

Means and Ranges of Body Weight and Linear Body Measurements of Sheep

Variable	*Sex*	*Range*	*Mean*	*SE*
Body weight, kg	M	20.0 - 58.0	32.6	1.99
(BWT)	F	20.0 - 45.0	28.7	0.56
Body length, cm	M	78.0 - 119.0	93.0	1.92
(BDL)	F	69.0 - 116.0	94.1	0.83
Width at hip, cm	M	25.0 - 42.0	31.0	0.81
(WHP)	F	23.0 - 40.0	30.8	0.28
Width at shoulders, cm	M	22.0 - 38.0	28.6	0.79
(WSD)	F	23.0 - 36.0	28.5	0.25
Heart girth, cm	M	60.0 - 97.0	78.2	1.90
(HGR)	F	60.0 - 91.0	76.3	0.52
Height at withers, cm	M	53.0 - 82.0	67.3	1.41
(HWI)	F	54.0 - 86.0	67.7	0.58
Head length, cm	M	22.0 - 38.0	26.7	0.72
(HDL)	F	23.0 - 33.0	27.3	0.18
Rump length, cm	M	56.0 - 89.0	70.7	1.41
(RUL)	F	52.0 - 86.0	71.1	0.61
Tail length, cm	M	22.0 - 49.0	31.3	1.40
(TAL)	F	18.0 - 50.0	33.2	0.59

that were higher in females than in males. The males had higher chest circumference (78 cm) than females (76 cm) which was measured with the heart girth. However, males and females had the same measure for width-at-hip (31 cm), width-at-shoulder (29 cm), and height-at-withers (67 cm).

Table 2 shows the correlation coefficients between the variables. Correlation coefficients between body weight and width-at-hip, width-at-shoulder and heart girth are high and significant, which suggests that either any of these variables or their combination, would provide a good estimate for predicting liveweight in sheep. Mukherjee *et al.* (1981, 1986) and Singh *et al.* (1987) reported the highest correlation value of body weight with chest circumference in various Indian goat breeds. In adult animals, body length assumes more importance as an indicator of liveweight. Osinowo *et al.* (1989) also found that heart girth gave the best estimate for predicting liveweight of Nigerian Red Sokoto goats at 1-2 years of age, but body length was a better predictor at later stages. Working with cattle and sheep breeds in Ghana, Balig (1970) and Ahunu & Kpesese (1995) showed a strong relation between heart girth and liveweight. Hassan & Giroma (1992) indicated that based on the magnitude of the correlation coefficients, body length and height-at-withers could be used to predict liveweight of Red Sokoto goats. Their analyses also indicated significant sex effect on the linear body measurements, therefore stressing the need not to ignore sex in using any linear body measurement to predict liveweight in sheep and goats.

Predictive equation for body weight

From the regression analysis, fitting all the variables in a full model, only BDL, WSD, HGR and SEX were significant ($P<0.05$ and $-1.96 < t < 1.96$) (Table 3). It should be noted that contrary to

TABLE 2

Correlations Between Linear Body Measurements and Live Body Weight of Sheep

	BWT	*BDL*	*WHP*	*WSD*	*HGR*	*HWI*	*HDL*	*RUL*
BDL	0.668							
WHP	0.746	0.645						
WSD	0.732	0.603	0.744					
HGR	0.830	0.639	0.746	0.687				
HWI	0.701	0.622	0.698	0.764	0.675			
HDL	0.525	0.393	0.574	0.585	0.545	0.614		
RUL	0.714	0.685	0.744	0.719	0.668	0.884	0.564	
TAL	0.490	0.569	0.495	0.543	0.468	0.728	0.466	0.748

TABLE 3

Regression Analysis - Full Model

Predictor	*Coef*	*StDev*	*T*	*P*
Constant	-51.0030	4.2340	-12.04	0.000
BDL	0.0929	0.0425	2.19	0.030*
WHP	0.2036	0.1484	1.37	0.172
WSD	0.3876	0.1523	2.55	0.012*
HGR	0.4912	0.0676	7.27	0.000*
HWI	0.0084	0.1017	0.08	0.934
HDL	0.0885	0.1461	0.61	0.546
RUL	0.1589	0.0947	1.68	0.095
TAL	0.0324	0.0760	0.43	0.670
SEX	2.3817	0.8103	2.94	0.004*
BREED 1	0.3730	1.2970	0.29	0.774
BREED 2	2.3240	1.2020	1.93	0.055

* ($P < 0.05$ and $-1.96 < t < 1.96$)

general expectation, the type of breed as a predictor did not have any significant effect on the liveweight of sheep (Table 3), especially when up to six variables are considered in a predictive model (Table 4). As fewer numbers of variables were considered in the final predictive model, the effect of breed type on liveweight was unimportant. Table 4 shows the results of selection of predictive models by the "All Possible Selection" procedure. An *X* sign against a variable indicates that it is included in the model. It can be observed that the coefficient of determination, R^2 (which measures the proportion of variation (%) accounted for by the variable(s) included in the model), increased from 68. 7 per cent in a l-variable model up to about 78 per cent as more variables were added. Also shown for each model is the Mallow's constant, *Cp*, which gives a bias in prediction.

The optimum model

Predictive equations with fewer variables are simple and easy to interpret. One of the variables, HGR, which gives a measure of the cross-sectional area, has the highest correlation (0.83) with body weight (Table 2). Also, considering that HGR and WSD are closely related as both give a measure of the cross-sectional area and, therefore, show a high collinearity, WSD can be dropped from model without much effect. Taking weight as a function of volume, which , in turn, is a function of length and cross-sectional area, a new variable can be developed to take account of volume based on $(HGR)^2$ and BDL. This new variable, given as $[(HGR)^2 \times BDL]$, is referred to as the *index of volume* (Gordor & Howard, 1999). Consequently, the general form of the body weight model proposed is as follows:

$$BWT = \beta_0 + \beta_1 [(HGR)^2 \times BDL] + \beta_2 SEX$$

Based on the data available, the final predictive equation for liveweight is then:

TABLE 4

Results Based on the "All Possible Selection" Method

No. of predictors	R^2 *%*	*Cp*	*BDL*	*HGR*	*WSD*	*WHP*	*HWI*	*HDL*	*RUL*	*TAL*	*SEX*	*BREED 1*	*BREED 2*
1	68.7	71.5		*X*									
2	72.3	35.3		*X*	*X*								
3	73.6	24.6		*X*	*X*						*X*		
4	74.9	10.5	*X*	*X*	*X*						*X*		
5	76.8	8.1	*X*	*X*	*X*						*X*		
6	77.1	4.7	*X*	*X*	*X*				*X*		*X*		*X*
7	78.2	4.8	*X*	*X*	*X*	*X*			*X*		*X*		*X*
8	78.1	6.4	*X*	*X*	*X*	*X*		*X*	*X*		*X*		*X*
9	78.0	8.1	*X*	*X*	*X*	*X*		*X*	*X*	*X*	*X*		*X*
10	77.8	10.0	*X*	*X*	*X*	*X*	*X*	*X*	*X*	*X*	*X*		*X*
11	77.6	12.0	*X*	*X*	*X*	*X*	*X*	*X*	*X*	*X*	*X*	*X*	*X*

* ($P < 0.05$ and $-1.96 < t < 1.96$)

$$BWT = 5.02 + 4.3 \times 10^{-5} [(HGR)^2 \times BDL] + 2.48\ SEX$$

with a coefficient of determination R^2 of about 76.2 per cent which is reasonably high. This showed an improvement in the R^2 of about 74.9 per cent for the model incorporating HGR and BDL as well as SEX as separate independent variables. This is because the new predictor variable that considers volume of an animal by its chest circumference and body length, is responsible for

TABLE 5

Weight Chart Developed from Predictive Equation Based on [(HGR)² × BDL] and SEX

BDL (cm)	*SEX*	*HGR (cm)*				
		71	72	73	74	75
	M	27.0	27.5	28.1	28.7	29.3
		(25.5 - 28.5)	(26.1 - 29.6)	(26.7 - 29.6)	(27.2 - 30.1)	(27.8 - 30.7)
91	F	24.5	25.1	25.6	26.2	26.8
		(23.8 - 25.2)	(24.4 - 25.8)	(24.9 - 26.3)	(25.5 - 26.9)	(26.1 - 27.4)
	M	27.2	27.8	28.3	28.9	29.5
92		(25.7 - 28.7)	(26.3 - 29.2)	(26.9 - 29.8)	(27.5 - 30.3)	(28.1 - 31.5)
	F	24.7	25.3	25.9	26.4	27.0
		(24.0 - 25.4)	24.65 - 26.0)	(25.2 - 26.5)	(25.8 - 27.1)	(26.4 - 27.7)
	M	27.4	28.0	28.6	29.1	29.7
		(26.0 - 28.9)	(26.5 - 29.4)	(27.1 - 30.0)	(27.7 - 30.6)	(28.3 - 31.1)
93	F	24.9	25.5	26.1	26.7	27.3
		(24.2 - 26.5)	(24.8 - 26.2)	(25.4 - 26.8)	(26.0 - 27.3)	(26.6 - 27.9)
	M	27.6	28.2	28.8	29.4	30.0
		(26.2 - 29.1)	(26.8 - 29.6)	(27.4 - 30.2)	(27.9 - 30.8)	(28.6 - 31.4)
94	F	25.2	25.7	26.3	26.9	27.5
		(24.5 - 25.9)	(25.0 - 26.4)	25.6 - 27.0)	(26.2 - 27.5)	(26.8 - 28.1)
	M	27.8	28.4	29.0	29.6	30.2
		(26.4 - 29.3)	(27.0 - 29.9)	(27.6 - 30.4)	(28.2 - 31.0)	(28.8 - 31.6)
95	F	25.4	25.9	26.5	27.1	27.7
		(24.7 - 26.1)	(25.3 - 26.6)	(25.9 - 27.2)	(26.5 - 27.8)	(27.1 - 28.3)
	M	28.1	28.7	29.2	29.8	30.4
		(26.6 - 29.5)	(27.2 - 30.1)	(27.8 - 30.7)	(28.4 - 31.3)	(29.1 - 31.9)
96	F	25.6	26.2	26.8	27.4	28.0
		(24.9 - 26.3)	(25.5 - 26.8)	(26.1 - 27.4)	(26.7 - 28.0)	(27.4 - 28.6)
	M	28.3	28.9	29.5	30.1	30.7
		(26.8 - 29.7)	(27.4 - 30.3)	(28.1 - 30.9)	(28.7 - 31.5)	(29.3 - 32.1)
97	F	25.8	26.4	27.0	27.6	28.2
		(25.1 - 26.4)	(25.7 - 27.0)	(26.3 - 27.6)	(27.0 - 28.3)	(27.6 - 28.8)
	M	28.5	29.1	29.7	30.3	30.9
		(27.1 - 29.9)	(27.7 - 30.5)	(28.3 - 31.1)	(28.9 - 31.7)	(29.5 - 32.3)
98	F	26.0	26.6	27.2	27.8	28.4
		(25.3 - 26.7)	(25.9 - 27.3)	(26.6 - 27.8)	(27.2 - 28.5)	(27.8 - 29.1)
	M	28.7	29.3	29.9	30.5	31.2
		(27.3 - 30.1)	(27.9 - 30.7)	(28.5 - 31.3)	(29.1 - 31.9)	(29.8 - 32.5)
99	F	26.2	26.8	27.4	28.1	28.7
		(25.6 - 26.9)	(26.2 - 27.5)	(26.8 - 28.1)	(27.4 - 28.7)	(28.1 - 29.3)
	M	28.9	29.5	30.1	30.8	31.4
		(27.5 - 30.3)	28.1 - 30.9	(28.7 - 31.6)	(29.4 - 32.2)	(30.0 - 32.8)
100	F	26.4	27.0	27.7	28.3	28.9
		(25.8 - 27.1)	(26.4 - 27.7)	(27.0 - 28.3)	(27.7 - 28.9)	(28.3 - 29.5)

much variation in the liveweight. Thus, given the sex of an animal and an index of volume based on its HGR and BDL, the animal's body weight can be predicted from the model with a much higher level of accuracy.

Weight chart

The weight of a sheep may be predicted based on the aforementioned optimum model; and from this a weight chart can be constructed. Table 5 shows a portion of the weight chart developed, based on HGR spanning from 71 to 75 cm, and on BDL spanning from 91 to 100 cm, for male and female animals, separately. For a given HGR and a corresponding BDL, the first number represents the predicted weight of animal given the sex, and the corresponding numbers in parentheses indicate the 95 per cent confidence interval for the predicted weight. As an example, for a sheep with a heart girth of 71 cm and a body length of 91 cm, the predicted liveweight for a male animal is 27.0 kg with a 95 per cent CI of 25.5 - 28.5 kg. The corresponding weight for a female animal is 24.5 kg with a 95 per cent CI of 23.8 - 25.2 kg. From the weight chart developed by MOFA, an animal with a heart girth measure of 71 cm will weigh 25.3 kg regardless of the sex of the animal. The present weight chart, therefore, seems more appropriate than the one developed by MOFA which is based on only HGR.

Further investigations should be carried out to include measurements on very young and growing animals to obtain the optimum predictive model covering all age groups. Appropriate weight charts based on HGR and BDL could then be constructed to easily determine liveweights for different classes of sheep.

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