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Predicting the body mass of goats from body measurements

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Abstract

This paper deals with designing a cheap and easy-to-attain method to replace weighing for estimating the body mass of goats. Several models on the relationship of heart girth (HG) to live weight (LW) were evaluated using Creole of Guadeloupe goats (376 males and 258 growing females). The best fit was obtained with a Gompertz model: $LW = 155 * exp(-7.91 * exp(-0.0215 * HG))$, which provided an adjusted $R^2 = 0.98$ and a 95% confidence interval of the prediction values below 5% within most of the LW range.

The LW of breeding goats (420) was fitted by the following quadratic model taking into account the HG and paunch girth (PG):

$$LW = -28.1 + 0.539 * HG + 0.00221 * PG^2,$$

which provided an adjusted $R^2 = 0.95$ and a 95% confidence interval of the prediction values below 1% within most of the LW range. The first model allows a tape measure graduated in kg to be used on goats except breeding females. The second model allows the building of an abacus to provide the estimated LWs of breeding goats from the HG and PG values. Further correction might be achieved by adding the goat body condition score. Such cheap tools should be very useful for goat farmers, most of whom lack reliable weighing devices.

Keywords: Body condition score, Creole goat, heart girth, live weight, paunch girth

Introduction

Knowing the body mass of small ruminants is very useful for good animal management, including understanding medication doses, adjusting feed supply, monitoring growth and choosing replacement males and females. The most intuitive way to assess body mass is weighing animals with a spring balance, a steelyard balance or any suitable scale. However, such devices are too expensive for most of small farmers. Using spring or steelyard balances can be painful because animals need to be lifted up. The spring in the scale can permanently stretch with repeated or out-of-bounds use, resulting in biased measurement. Scales must be installed on a horizontal base (concrete floor) and checked regularly for setting and calibration. Any defect in the base building can result in a bias in the measurements, as well as any lack of calibration. Scale calibration and maintenance require skilled technicians. Therefore, the conditions for accurate weighing are seldom met in the field. Moreover, the live weight (LW) is only an estimation of body mass because it varies continuously with feeding, watering, dropping, urinating, breathing, sweating and so on.

The various lengths, heights and girths of live animals are measured to assess the relationship between these variables and the LW, in cattle (Dineur and Thys 1986; Goe et al 2001; Mekonnen and Biruk 2004; Abdelhadi and Babiker 2009), in sheep (Valdez et al 1997; Atta and El khidir 2004; Sowande and Sobola 2008; Kunene et al 2009; Oke and Ogbonnaya 2011) or goat (Mohammed and Amin 1997; Nsoso et al 2004; Adeyinka and Mohammed 2006; Fajemilehin and Salako 2008). However, most of the authors dealt with breed characterization rather than providing farmers with practical tools. Moreover, some of these measurements require accurate knowledge of the anatomy (i.e. body length) or adapted tools (i.e. height and width). For these reasons, this paper deals with girth measurements that are cheap and easy-to-attain for most farmers, and could help in monitoring weight of both growing and breeding goats.

The first aim of this paper is to evaluate the short-term variability of LW and heart girth (HG) values measured on the same individuals. The second aim is to study the relationship between the LW and HG or, if needed, a linear combination of the heart and paunch girth (PG), and build tools for predicting the LW from easy-to-attain body measurements.

Materials and methods

All data were collected at the INRA experimental unit in Guadeloupe (FWI, 16°18 N, 61°19 W). The Creole of Guadeloupe goat is a meat-type, medium-sized animal derived mainly from the West African goat introduced during the colonial era. Every goat from the herd was measured at least once during the routine weighing operation. The HG and abdominal circumference, or the PG, measurements were done with a tape measure, as illustrated in Figure 1. The LW was measured with an electronic scale laid on a concrete floor. The measurement uncertainty was estimated to be about 1 cm for the HG and 0.05 kg for the LW.

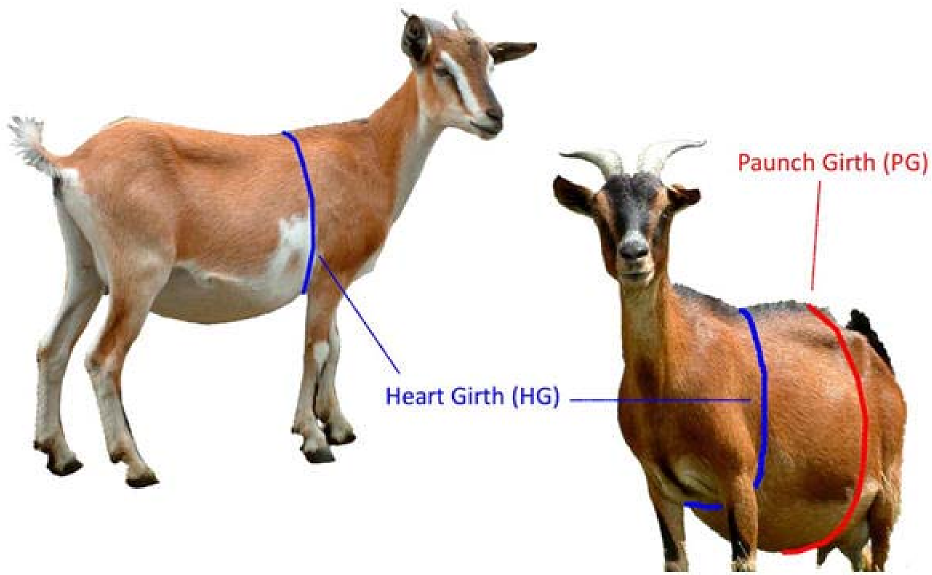

Figure 1. Heart girth and paunch girth measurement

Data collection for the study of the variability of LW and HG measurements

LW and HG measurements were taken twice at a three-day interval: the last day the animals spent in a given paddock and two days after they were allowed to graze a new one. Fifty-four goats aged from five days to 12 years were randomly chosen for this study. The LW and HG ranged from 2.05–49.6 kg and 29–87 cm, respectively.

Data collection for the study of the LW to HG relationship

Weight and HG measurements were taken from 609 growing male and female goats (less than one-year-old) and 36 adult male goats (over one-year-old). We supposed that the large variations in the LW were because pregnancy can diminish the accuracy of the HG to LW relationship in adult goats, and we analysed these data separately.

Data collection for validation

A review of the available literature allowed the collection of data on both the HG and LW from 18 papers. The data were plotted and the fit of the "Creole of Guadeloupe goat equation" was checked. The bias of prediction, i.e. the difference between the LW predicted from the HG and the LW provided by the authors, was tabulated.

Data collection for the study of the LW to HG and PG relationship in the adult goats

For the adult goats, the PG measurement was added to the set of data. Altogether, 425 pieces of HG and PG data were obtained from 237 animals. The goats were measured just before and just after parturition, or about mid-pregnancy. Additionally, 178 body condition score data (arbitrary scale: "A" to "E" from the fattest to the thinnest) were collected.

Statistical analyses

The individual differences between the two successive measurements divided by the mean of these measurements was computed for the comparison of the variability of the LW and HG measurements. The values obtained were compared by using a paired one-sided *t* test. Several non-linear models were compared on the whole dataset from males or growing animals, by examining the adjusted R^2 of the expected linear regression between fitted and measured values of the LW. The models were:

Allometric: $LW = a * HG^b$

Quadratic: $LW = a_0 + a_1 * HG + a_2 * HG^2$

Cubic: $LW = a_0 + a_1 * HG + a_2 * HG^2 + a_3 * HG^3$

Gompertz: $LW = a * exp(b * exp(c * HG))$

Mitscherlich: $LW = a + (b * exp(c * HG))$

The residuals of the better model were used for discarding 11 outliers, probably corresponding to errors in the measurement and recording process. Then, the models were run and compared again on the clean dataset (376 male and 258 female goats). The final data distribution is illustrated in Figure 2 (left).

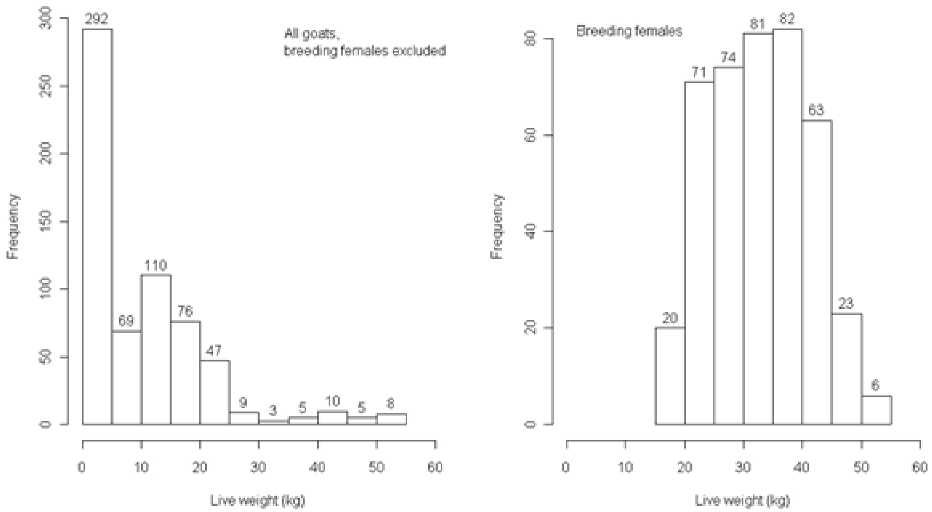

Figure 2. Live weight data distribution in growing goats and adult male goats (left) and in breeding female goats (right)

The prediction accuracy of the two best fitting models was then assessed using a simple cross validation (Mosteller and Tukey 1987). This procedure consists of splitting up the sample data into two randomly build subsets, whereby the first subset (three-quarters of the whole set) serves to estimate the non-linear regression parameters and predict the values in the second subset. This method was repeated 2000 times. Each time the adjusted R^2 of the prediction and validation values was collected. The predicted LWs corresponding to an artificial HG dataset (1 cm intervals from the minimum to the maximum value of the whole HG dataset) were also collected. For each value of the artificial HG set, the corresponding 0.025 and 0.975 quantiles (Q0.025and Q0.975, respectively) of the LW estimates were computed for providing the 95% confidence interval (CI95) of prediction. The accuracy of the models was compared by plotting the ratio of the CI95/LW estimate (ie: $(Q0.0975 - Q\ 0.025)/(Q0.975 + Q\ 0.025)/2)$ against the corresponding LW estimate values (i.e. $(Q.975+Q.025)/2)$. Additionally, the residuals were submitted to a Shapiro–Wilk normality test and an ANOVA (Tukey test) to check for a possible sex effect.

For the adult female goat data, two models were compared. The first used a Gompertz function fitted to a linear combination of the HG and PG values:

$$LW = a * exp(b * exp(c * (d * HG + (1 - d) * PG)))$$

The d coefficient was chosen to minimize the residual of the model, with $0 \leq d \leq 1$. The second model used a quadratic function defined as:

$$LW = a_0 + a_{11} * HG + a_{12} * HG^2 + a_{21} * PG + a_{22} * PG^2$$

The quadratic model was further simplified by deleting the coefficients that were not significantly different from zero to allow a better estimation of the remaining coefficients. The models were run and the residual distribution observed. Then, the 5 outliers were discarded and the models were run again for the final parameter calculation. The data distribution is illustrated in Figure 2 (right).

After choosing the best model, the residuals were submitted to a Shapiro–Wilk normality test and then to an ANOVA (Tukey test) with the BCS as the factor. Because of the BCS data distribution (3, 85, 155, 4 and 0 individuals for the BCS classes "A", "B", "C", "D" and "E", respectively), the classes "A" and "B" were pooled together, as were the "C", "D" and "E" classes. The same method as before was used for the cross validation of these two models.

All calculations were done by using the R statistical software (R_Development_Core_Team 2009). The model parameters were estimated by using the nls function from the R Stats package. The

ANOVA and Tukey tests were performed by using the R Agricolae package.

Results and discussion

Variability of LW and HG

The relative uncertainty in measuring the HG varied from about 5% for the smaller animals to 1.25% for the largest. The relative uncertainty in measuring the LW ranged theoretically from 2.5% for the smaller animals to 0.1% for the largest. Despite these statements, the variability of the BW measurement in the same animals (Figure 3) was significantly higher than the variability of the HG (4.51% vs. 2.65 %, respectively, $p = 0.0009$, paired t test, one-sided). These differences in the same animals were mainly because of the variations in digestive tract content. This indicates that the HG should be a more reliable estimation of body mass than the LW.

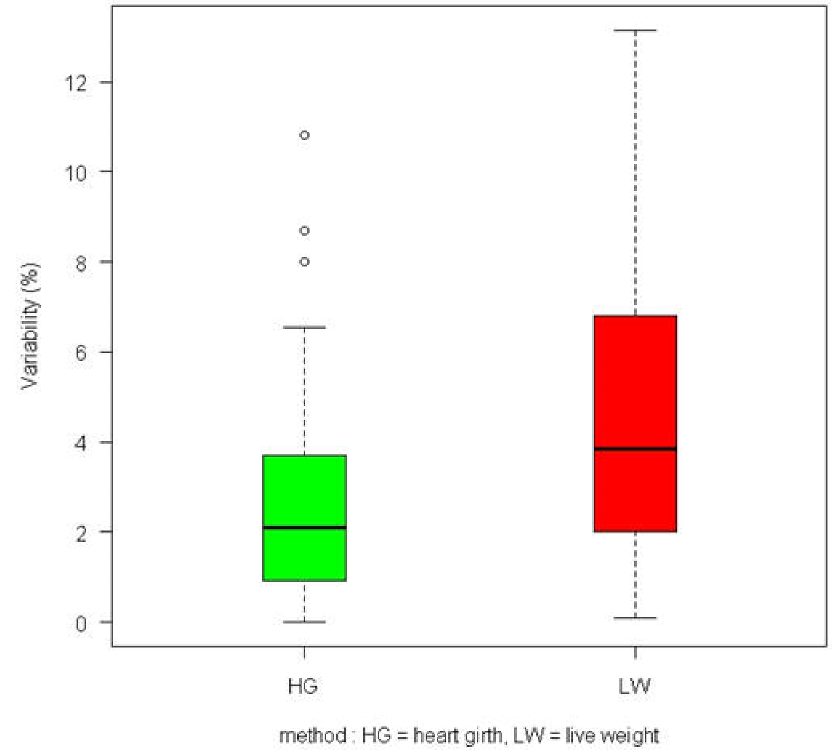

Figure 3. Variability of the body mass estimation according to the measurement method

LW to HG relationship

Comparison of the models

The five models shown in Figure 4 fitted the dataset well ($R^2 = 0.98$). However, focussing on the young animals allowed us to discard the allometric and Mitscherlich models, which seemed to fit the corresponding values less accurately. Moreover, the quadratic and cubic models were practically the same because the last coefficient of the cubic model did not differ significantly from zero. Therefore, the quadratic and Gompertz models were used for further analyses (cross validation).

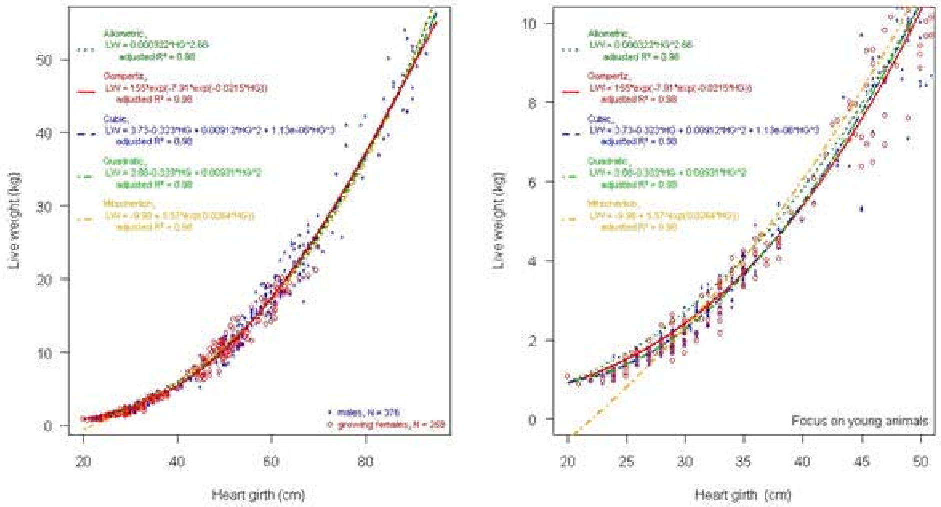

Figure 4. Live weight to Heart girth relationship in Creole Goat of Guadeloupe, adult breeding goat excluded. Comparison of non-linear regression models on the whole data set (left). Focus on young animals (right).

Cross validation of the Gompertz and quadratic models

The cross validation of the Gompertz and quadratic models yielded very similar figures. The adjusted R^2 of the prediction and validation values were always above 0.97. The accuracy of the two models (Figure 5) was also very similar for the values above 10 kg LW, with an empiric confidence interval below 5% of the estimated LW. However, Figure 5 shows that, despite the number of animals weighing less than 10 kg LW that were used for the parameter calculations (Figure 2), the quadratic model was less accurate than the Gompertz one, and this cannot be linked to the uncertainty in the measurements (about 1 cm for HG, about 0.05 kg for LW). For this reason, the Gompertz model seemed to be the best.

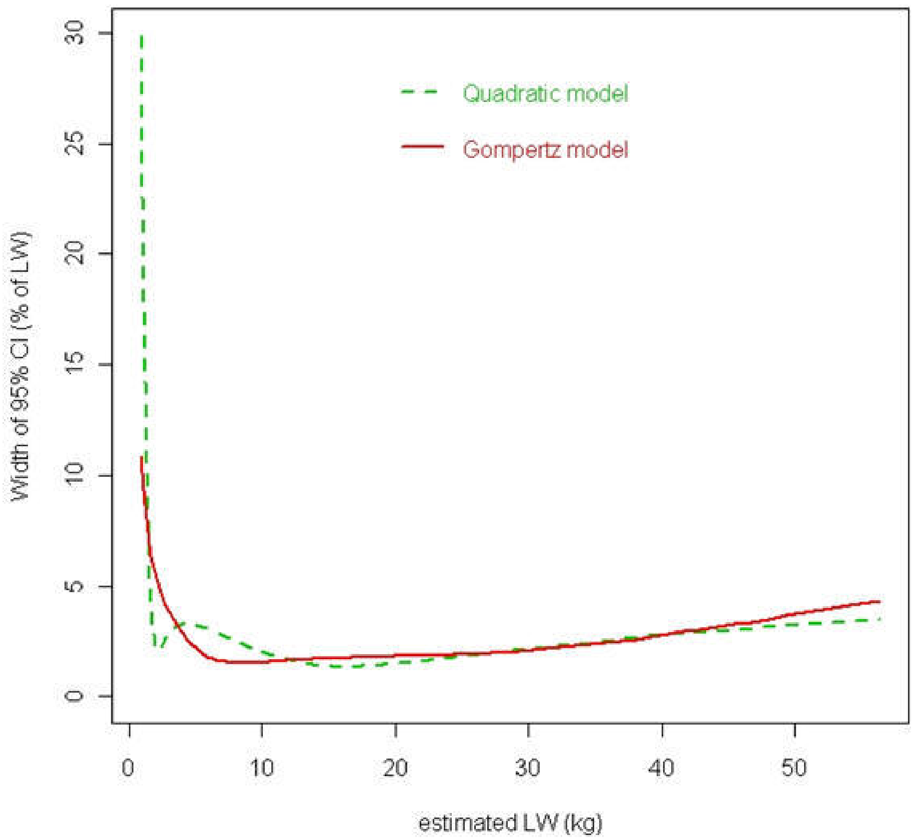

Figure 5. Width of the empiric 95% confidence interval of prediction of LW from Heart Girth, expressed as a percentage of the estimated live weight (cross validation, 2000 re-samplings)

There was no sex effect on the HG to LW relationship ($p = 0.3$), so there was no need for gender correction.

Validation with other breed data from the literature

Table 1. Bias in the prediction of the LW from the HG with the "Creole of Guadeloupe goat equation" applied to data published

Breed	N data	Data type	Bias (kg)	Bias (percent of LW)	Reference
Beetal	5	Mean	–1.63	–5.4	Fida (2006)
Bengal	2	Mean	1.29	10.4	Khan (1992)
Borno	72	Mean	–0.347	–3.2	Mohammed (1997)
Carpathian	2	Mean	–0.20	–1.1	Cighi (2008)
Chaugarkha	8	Mean	–0.35	–4.3	Singh (2007)

Mexico Native	1	Mean	3.12	10.5	Vargas (2007)
Mexico Native*Nubian	2	Mean	5.75	16.7	Vargas (2007)
Moxoto	1	Mean	–10.07	–50.2	Ribeiro (2004)
Osmanabadi	18	Mean	0.23	3.0	Kochewad (2009)
Rajasthan crossbred	4	Mean	0.97	5.4	Yadav (2007)
Saanen	2	Mean	–1.9	–3.6	Pesmen (2008)
Saanen*Boer	3	Mean	–1.35	–7.6	Menezes (2007)
Tibetan	2	Mean	2.00	6.1	Shrestha (1992)
Tswana	12	Mean	–2.95	–9.6	Nsoso (2004)
Tswana	6	Mean	–0.12	–0.1	Nsoso (2003)
West African Dwarf (WAD)	3	Mean	–0.934	–9.5	Ojedapo (2007)
WAD	7	Mean	–1.55	–17.5	Fajemilehin (2008)
Borno	2	Mean	–3.0	–52.2	Adeyinka (2006)
Sokoto	2	Mean	–3.2	–59.2	Adeyinka (2006)

The Creole goat equation fitted most of published data well with an adjusted R^2 of 0.97 (Figure 6). Because of the non-linear relationship between the HG and LW, the LW mean could be underestimated by the mean of HG, at least when the means were calculated from animals that were different in size (Nsoso et al 2004; Ribeiro et al 2004). When the HG and LW means were calculated with data from homogeneous groups they fitted very well (Mohammed and Amin 1997; Nsoso et al 2003; Kochewad et al 2009). However, some of the published data were poorly predicted by the model (Table 1) and this could be because of actual differences in the body shape or bias in the data (faulty weighing device or tape).

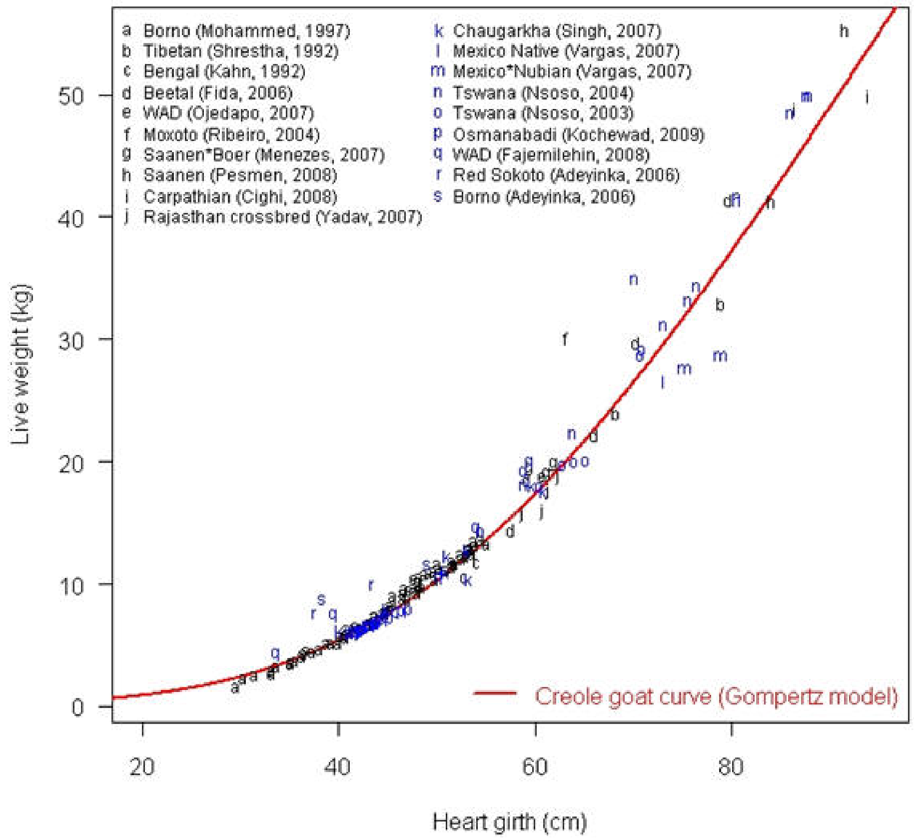

Figure 6. Live weight according to Heart girth data from various goat breeds in the literature

Moreover, the Gompertz or quadratic models fitted the dataset collected on the adult breeding goats rather poorly (adjusted $R^2 = 0.83$), probably because of the large variations in the LW due to the stage of pregnancy, which did not alter the HG. This, therefore, justified combining the HG and PG measurements.

LW to HG and PG relationship in the adult goats

Both models fitted the dataset evenly (adjusted $R^2 = 0.95$; Figure 7). The cross validation also yielded similar figures for the two models (adjusted R^2 of prediction values ranging from 0.94 to 0.95, adjusted R^2 of validation values ranging from 0.93 to 0.96). However, Figure 8 indicates that the quadratic model provided a narrower CI95 along the weight range than did the Gompertz model, which prefers the quadratic model for body mass estimation in breeding goats.

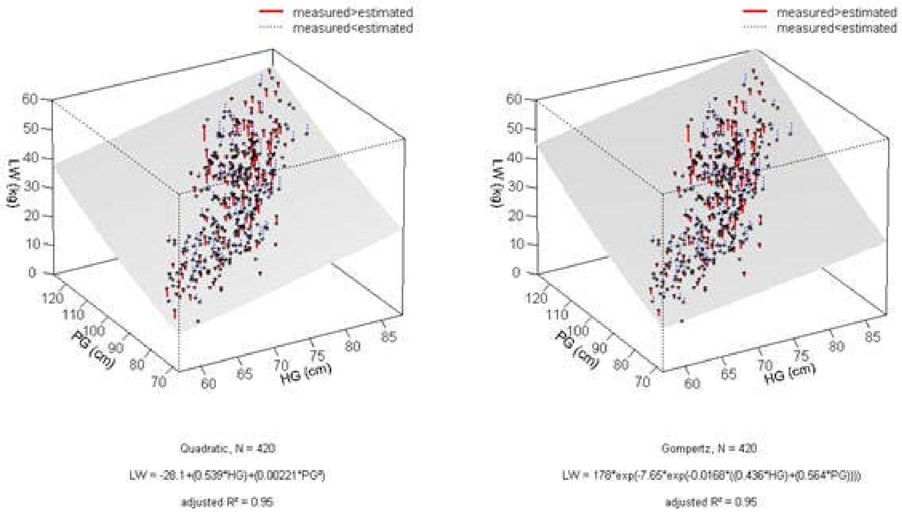

Figure 7. 3-D plot of measured (*) and estimated (grey surface) live weight, quadratic model (left) and Gompertz model (right)

The distribution of the quadratic model residuals was Gaussian (p = 0.64, Shapiro–Wilk normality test), as well as the distribution of the relative residuals (residual/fitted values, expressed as a percentage, p = 0.34). The ANOVA provided the following estimates of the effects of the BCS, which might increase the accuracy of the body mass prediction from the body measurements of the HG and PG. The goats with "A" or "B" BCS were on average 1.5% heavier than their estimated LW (i.e. +0.63 kg), whereas the goats with "C" or "D" BCS were on average 1.2% lighter (–0.44 kg), and this BCS effect was highly significant (p = 0.00014). Larger corrections would probably be expected for the animals with "A", "D" or "E" BCS, but this would require additional measurements of such animals to confirm.

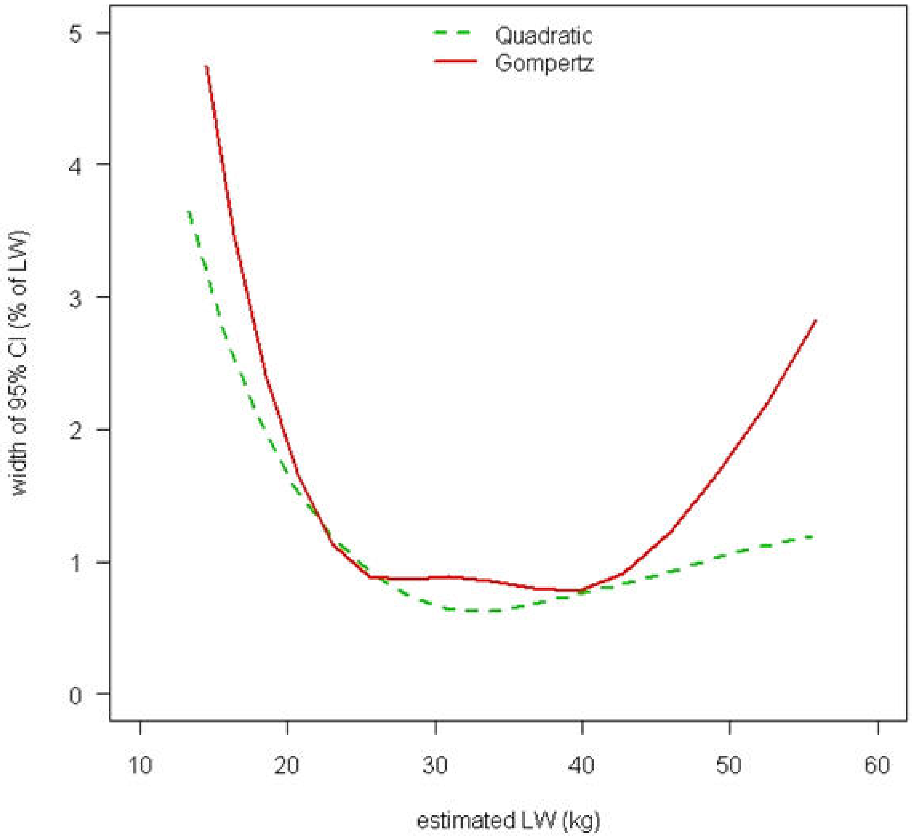

Figure 8. Width of the empiric 95% confidence interval of prediction of LW from Heart and Paunch Girth, expressed as a percentage of the estimated live weight (cross validation, 2000 re-samplings).

Practical

The following Table 2 allows either designing a tape graduated in kg on one side and cm on the other side, or using a standard tape and converting the HG measure to LW. Such tape could be used for estimating the live weight of growing or male goats up to about 50-55 kg. The same tape graduated in cm could be used for estimating the adult goat live weight with the help of Table 3. For example, a breeding goat with HG = 71 cm and PG = 94 cm should weigh about 29.5 kg. For the measures falling between two values of the table, the live weight could be estimated by interpolation.

Table 2: HG (cm) and LW (kg) corresponding values for male or growing goats

Heart Girth (cm)	Live Weight (kg)	Heart Girth (cm)	Live Weight (kg)	Heart Girth (cm)	Live Weight (kg)
20.4	0.9	40.7	5.6	64.2	21
21.4	1	41.2	5.8	64.7	21.5
22.3	1.1	41.6	6	65.3	22

23.1	1.2	42.1	6.2	65.8	22.5
23.9	1.3	42.6	6.4	66.3	23
24.6	1.4	43	6.6	66.9	23.5
25.3	1.5	43.4	6.8	67.4	24
25.9	1.6	43.9	7	67.9	24.5
26.5	1.7	44.3	7.2	68.4	25
27.1	1.8	44.7	7.4	68.9	25.5
27.7	1.9	45.1	7.6	69.4	26
28.2	2	45.5	7.8	69.9	26.5
28.7	2.1	45.9	8	70.4	27
29.2	2.2	46.3	8.2	70.9	27.5
29.7	2.3	46.7	8.4	71.4	28
30.2	2.4	47.1	8.6	71.9	28.5
30.6	2.5	47.4	8.8	72.4	29
31.1	2.6	47.8	9	72.9	29.5
31.5	2.7	48.1	9.2	73.3	30
31.9	2.8	48.5	9.4	74.3	31
32.3	2.9	48.8	9.6	75.2	32
32.7	3	49.2	9.8	76.1	33
33.1	3.1	49.5	10	77	34
33.5	3.2	50.4	10.5	77.9	35
33.8	3.3	51.2	11	78.8	36
34.2	3.4	52	11.5	79.7	37
34.6	3.5	52.7	12	80.6	38
34.9	3.6	53.5	12.5	81.5	39
35.2	3.7	54.2	13	82.3	40
35.6	3.8	54.9	13.5	83.2	41
35.9	3.9	55.6	14	84.1	42
36.2	4	56.3	14.5	84.9	43
36.5	4.1	57	15	85.8	44
36.8	4.2	57.6	15.5	86.6	45
37.1	4.3	58.3	16	87.5	46
37.4	4.4	58.9	16.5	88.3	47
37.7	4.5	59.5	17	89.1	48
38	4.6	60.1	17.5	90	49
38.3	4.7	60.7	18	90.8	50
38.6	4.8	61.3	18.5	91.6	51
38.8	4.9	61.9	19	92.5	52
39.1	5	62.5	19.5	93.3	53
39.6	5.2	63.1	20	94.1	54
40.2	5.4	63.6	20.5	95	55

Table 3. Predicting live weight of goats from heart and paunch girth measurements

Live weight (kg)	Paunch Girth (cm)																			
Heart Girth (cm)	**67**	**70**	**73**	**76**	**79**	**82**	**85**	**88**	**91**	**94**	**97**	**100**	**103**	**106**	**109**	**112**	**115**	**118**	**121**	**124**
55	12.0	12.5	13.5	14.5	16.0	17.0	18.0	19.0	20.5	21.5	23.0	24.5	25.5	27.0	28.5	30.0	31.5	33.0	35.0	36.5
57	13.0	13.5	14.5	15.5	17.0	18.0	19.0	20.0	21.5	22.5	24.0	25.5	26.5	28.0	29.5	31.0	32.5	34.0	36.0	37.5
59	14.0	14.5	15.5	16.5	18.0	19.0	20.0	21.0	22.5	23.5	25.0	26.5	27.5	29.0	30.5	32.0	33.5	35.0	37.0	38.5
61	15.0	15.5	16.5	17.5	19.0	20.0	21.0	22.0	23.5	24.5	26.0	27.5	28.5	30.0	31.5	33.0	34.5	36.0	38.0	39.5
63	16.0	16.5	17.5	18.5	20.0	21.0	22.0	23.0	24.5	25.5	27.0	28.5	29.5	31.0	32.5	34.0	35.5	37.0	39.0	40.5
65	17.0	18.0	18.5	19.5	21.0	22.0	23.0	24.0	25.5	26.5	28.0	29.5	30.5	32.0	33.5	35.0	36.5	38.0	40.0	41.5
67	18.0	19.0	19.5	20.5	22.0	23.0	24.0	25.0	26.5	27.5	29.0	30.5	31.5	33.0	34.5	36.0	37.5	39.0	41.0	42.5
69	19.0	20.0	20.5	22.0	23.0	24.0	25.0	26.0	27.5	28.5	30.0	31.5	32.5	34.0	35.5	37.0	38.5	40.0	42.0	43.5
71	20.0	21.0	21.5	23.0	24.0	25.0	26.0	27.0	28.5	29.5	31.0	32.5	33.5	35.0	36.5	38.0	39.5	41.0	43.0	44.5
73	21.0	22.0	23.0	24.0	25.0	26.0	27.0	28.0	29.5	30.5	32.0	33.5	34.5	36.0	37.5	39.0	40.5	42.5	44.0	45.5
75	22.0	23.0	24.0	25.0	26.0	27.0	28.0	29.0	30.5	31.5	33.0	34.5	35.5	37.0	38.5	40.0	41.5	43.5	45.0	46.5
77	23.0	24.0	25.0	26.0	27.0	28.0	29.0	30.0	31.5	32.5	34.0	35.5	36.5	38.0	39.5	41.0	42.5	44.5	46.0	47.5
79	24.0	25.0	26.0	27.0	28.0	29.0	30.0	31.5	32.5	33.5	35.0	36.5	38.0	39.0	40.5	42.0	43.5	45.5	47.0	48.5
81	25.0	26.0	27.0	28.0	29.0	30.0	31.0	32.5	33.5	34.5	36.0	37.5	39.0	40.0	41.5	43.0	44.5	46.5	48.0	49.5
83	26.0	27.0	28.0	29.0	30.0	31.0	32.0	33.5	34.5	35.5	37.0	38.5	40.0	41.0	42.5	44.0	45.5	47.5	49.0	50.5
85	27.0	28.0	29.0	30.0	31.0	32.0	33.0	34.5	35.5	37.0	38.0	39.5	41.0	42.0	43.5	45.0	46.5	48.5	50.0	51.5
87	28.0	29.0	30.0	31.0	32.0	33.0	34.0	35.5	36.5	38.0	39.0	40.5	42.0	43.0	44.5	46.0	47.5	49.5	51.0	52.5
89	29.0	30.0	31.0	32.0	33.0	34.0	35.0	36.5	37.5	39.0	40.0	41.5	43.0	44.0	45.5	47.0	48.5	50.5	52.0	53.5
91	30.0	31.0	32.0	33.0	34.0	35.0	36.0	37.5	38.5	40.0	41.0	42.5	44.0	45.0	46.5	48.0	49.5	51.5	53.0	54.5
93	31.0	32.0	33.0	34.0	35.0	36.0	37.0	38.5	39.5	41.0	42.0	43.5	45.0	46.0	47.5	49.0	50.5	52.5	54.0	55.5

Conclusions

- The HG (males and growing females) or a combination of the HG and PG (adult breeding does) provides reliable estimations of the body mass of the Creole goat.
- The model parameter estimates allow either building a dedicated tape (graduated in kg LW) for the growing animals or a table (abacus) for the breeding goats.
- Such tools would be cheaper and easier to implement than the various different weighing apparatus currently in use. However, the parameters presented above were fitted for the Creole goat and require validation and correction for different breeds and body shapes.

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