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Research Article

Use of body measurements to estimate live weight of Lagune cattle in southern Benin

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Abstract: The objective of this study was to establish weight estimation equations from body measurements applicable to Lagune cattle. Live weight (LW), body length (BL), heart girth (HG), and withers height (WH) were recorded in 909 Lagune cattle (506 males and 403 females) aged from 0 to 45 months at the Samiondji Breeding Farm in southern Benin. The correlation of weight with the BL (males - 0.95, females - 0.80) or with the HG (males - 0.96, females - 0.97) was higher than with the WH (males - 0.92, females - 0.79). Several types of equations between the weight and the three body measurements were compared. The equations retained for the Lagune cattle were polynomial regressions of the predicted weight (Y) on the BL (x), the HG (z) and the WH (t): Y = -77.29 - 0.07x + 1.47z + 0.18t for males and Y = -1.31 + 1.74x + 1.77z - 1.99t for females. The coefficients of determination R^2 were 0.95 and 0.94 for the respective males and females, while the Mallows coefficients were identical Cp = 4.00. The residual means of differences between observed and predicted weight were small (2.6 vs. 4.2 kg for the respective males and females) indicating good accuracy of the estimates.
Keywords: Body length, Heart girth, Withers height, Weight, Lagune cattle, Benin.

INTRODUCTION

Indigenous cattle breeds of Benin, estimated at 2 222 000 head in 2014 [1] are classified in two majors subgroups: *Bos indicus* (7.7%) and *Bos taurus* (92.3%). The *Bos taurus* consists of Borgu (34%), Lagune (3.7%), Somba (0.3%) and different crossed breeds (55%) [2]. The Lagune cattle named Muturu (Nigeria), Mayombe or Dahomey (Democratic Republic of Congo) and Lagoon (Ghana), are of the smallest cattle breeds, usually black or black with white spots, black mucosa, eyelids and hoofs, described as the Dwarf Shorthorn breeds. Their adaptive features such as trypanosomosis resistant, parasitic disease and feeding behaviour enable them to cope with the savannah and humid tsetse-infested areas [3-4]. The limited knowledge of Lagune breeds cattle has hampered the development of technology to improve their productivity. Since the last decade, the drastic regression of Lagune cattle has been reported in Benin, due to indiscriminate slaughter, inappropriate husbandry techniques, lack of improvement and continuous interbreeding with zebu breeds. Without sustainable management, the Lagune cattle may become one of the threatened breeds in the next future.

Live weight forms the basis for a range of research and management activities including assessment of growth rates, responses of animals to different diets and environmental conditions and determination of feed requirements. Knowledge of animal weight and weight changes are also important in determining responses to genetic selection [5], and are a key management tool [5-8]. Farmers and livestock traders are not accurate at estimating cattle live weight, with underestimates of 46 % and overestimates of 25 % reported [9]. The most widely accepted method globally, of measuring live weight is using a calibrated electronic or mechanical scale. However, such equipment is not readily available in a smallholder farming context. The use of mobile livestock weighing scales requires a vehicle, staff and some facilities. It is impractical and costly [10].

An alternative method for estimating live weight is the use of body measurements. These measurements can be taken at lower costs (when labor costs are relatively low) with a simple measuring tape and may provide relative accuracy and consistency [11,12]. This estimation method does not have the rigor of a weighing. It is useful, however, because it requires only lightweight material, minimal labor and reduced restraint [10,13]. In addition, satisfactory accuracy can be expected from the use of body measurements in growing animals [10]. By modeling the growth curves of Lagune cattle with the Brody, Gompertz and Logistics models, live weight prediction equations according to body measurements have been developed [14]. These formulas were, however, determined for all age groups, decreasing the precision of the live weight estimate, hence the low coefficients of determination (73% for females and 81% for males) [14]. It has been established that the relationship between live weight and body measurements is highly dependent on age, sex and breed [10, 15, 16]. Moreover, these equations have not been validated to estimate the difference between the real and estimated weights. From all the above it appears that the development of models of weight prediction of Lagune cattle from body measurements taking into account gender and age classes will allow to estimate the weight of some animals with more precision. The objective of this study is to develop weight prediction models based on body measurements by age group and sex.

MATERIAL AND METHODS

Study environment

The study was carried out in the Samiondji Breeding Farm (SBF) located in the Zou Department and Zangnanado Commune, between 2° 22' and 2° 25' east longitude, 7° 25' and 7° 30' north latitude. It covers an area of 3600 hectares and is totally surrounded by the river Oueme. The climate of the maritime subequatorial type is characterized by a bimodal rainfall regime with two rainy seasons and two dry seasons: large and small rainy season from March to June and September to October, small and large dry season respectively from July to August and December to February [17]. Annual rainfall varies between 900 and 1100 mm [18]. The soils encountered in the area of the SBF include non-climatic raw mineral soils, poorly eroded non-climatic erosion soils; Tropical ferruginous soils as well as leached and slightly leached tropical ferruginous soils [18]. The vegetation of the farm is mainly dominated by savannah formations, to which are added plant formations of clear forests to *Lonchocarpus serieus* and *Anogeius leiocarpus* and forests galleries along the river Oueme.

Feeding and animal health monitoring

The method of rearing was of semi-intensive type. The herds consisted of lots, depending on the sex and age of the animals. The average annual number was 1480 head. The cattle spent the day on the pasture and at night in a park with drinking troughs and feeders. The diet was based mainly on the exploitation of natural grazing, the composition and the evolution of the forage value varied with rainfall and vegetation [18]. Biomass ingested came from several types of natural pastures: grazing *Andropogon sp*, *Anogeissus leiocarpus*, *Brachiaria falcifera*, *Combretum collinum*, *Hyparrhenia smithiana*, *Heteropogon contortus*, *Vitellaria paradoxa*, *Pseudocedrela kotschyi*, *Pterocarpus erinaceus*, *Terminalia macroptera*, *Lonchocarpus sericeus*. Only the unweaned animals and the sick received nutritional supplements in the rainy season. In the dry season and due to the decrease in available forage, all animals were given *ad libitum* hay from pasture and *Leucaena leucocephala* in green form, crop residues (corn straw, cotton waste, peanut vines, cowpea), cottonseed meal (two bags of 80 kg per week to 100 head) and lick *ad libitum* mineral supplement. The watering was *ad libitum*. Health monitoring was essentially based on the administration of trace elements and vitamins, anticoccidials, and application of internal and external deworming. Animals were regularly vaccinated against rinderpest, contagious bovine pleuropneumonia, pasteurellosis, according to the current national disease control program. Routine serological surveillance against brucellosis was carried out by the National Veterinary Laboratory. The specific treatments were applied against occasional illnesses depending on clinical cases.

Sampling

Weight prediction equations were developed from data collected from a total of 909 animals. This sample was composed of 506 males and 403 females in the 0-6 month age classes (102 males and 65 females) from 6 to 12 months (105 males and 83 females), 12 to 24 months 98 females) from 24 to 36 months (62 males and 95 females) and 36 to 45 months (77 males and 62 females). For the validation of the equations developed, 20 other animals (10 males and 10 females) of each age class were used. Pregnant cows and heifers and castrated males were spared by the study.

Material and Equipment

A concrete corridor park was used for the restraint of weaned or adult animals. A weighing scale with a capacity of 50 to 1500 kg and a sensitivity of 1 kg was used for the weighing of weaned or adult animals. A mobile rocker with a maximum span of 300 kg was allocated to unweaned animals. Two metric ribbons in centimeters (150 and 300 cm) and a measuring rod were used for the measurements. The restraining equipment of the adult animals was made of ropes.

Measurement and weighing

Three measurements were performed according to standardized techniques [5, 13, 19]:

- Body length (from the tip of the shoulder to the tip of the buttock);
- Heart girth (chest immediately behind the shoulders);
- Withers height (vertical distance between the ground and the apex of the tourniquet, immediately behind the hump, on the top of the *scapulum*).

Body measurements were taken after immobilization and keeping the animals in a non-forced position. The weighings took place in the morning, before the watering of the animals and immediately after the measurements. They were picked up when the animal was immobilized inside the weighing scale. The measurements and weighings were performed by the same person to minimize bias.

Statistical analysis

The data were edited with Excel 2013 and the correlation coefficients were estimated using the SAS 9.2 CORR procedure [20]. The models of prediction of the body weight according to the three body measurements (body length, heart girth and withers height) were developed in two stages:

The SAS 9.2 REG and NLIN procedures [20] were first used to determine the linear or nonlinear regression equations (polynomial, exponential, logarithmic or power) linking the weight (dependent variable) to each of the three recorded body measurements, considered as independent variables. Depending on the trend of point clouds between the weight and the measurements considered, the regressions listed above were respectively tested and the best equation retained was the one with the highest coefficient of determination.

The multiple stepwise ascending regression (SAS 9.2) [20] was used in a second step to develop weight prediction models from the three body measurements. This automated method introduced linear predictive measurements step by step into the model, starting with the one that is most correlated with the weight. At each step, the method added a new linear measurement which improved the accuracy of the equation. The choice of the equations was made from the Cp statistic described by Mallows [21] and the coefficient of determination R^2. The most accurate and reliable equation was characterized by a low Mallow coefficient Cp and a high R^2 coefficient of determination.

Validation of the developed models was carried out by comparing the actual weight with the estimated weight from the equations retained. The most accurate equation is the one with the mean of the differences between the actual weight and the estimated weight being the smallest. The validation of the developed equations was performed on a sample other than the one used to develop the weight prediction models.

RESULTS

Correlations between weights and body measurements

In all animals (males and females), the weight had evolved in the same direction and at approximately the same rate as the body length, the heart girth and the withers height (Figures 1 and 2).

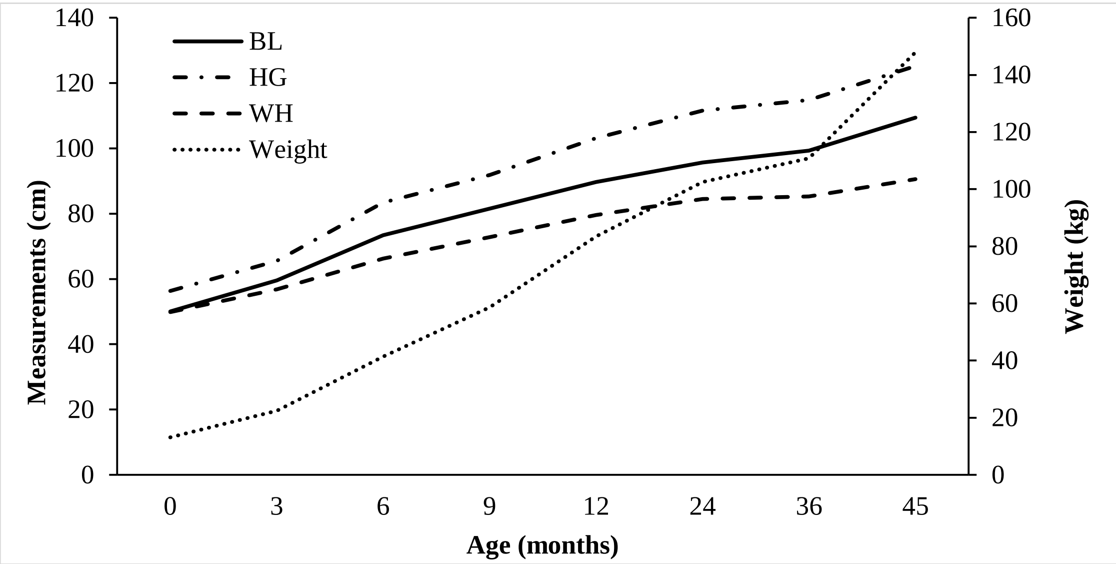

Fig-1: Evolution of linear measurements and weight in male Lagune cattle.

The correlations between weight and linear measurements were all significant (p<0.001) and ranged between 0.79 and 0.97, meaning that the different measurements were strongly correlated with weight. The greatest correlation was observed between weight and HG, both in males (r = 0.96) and in females (r = 0.97). The correlation between weight and BL was strong in males (r = 0.95) and lower in females (r = 0.80). The least significant correlation was observed between weight and WH, both in males (r = 0.92) and females (0.79).

Prediction of the weight of the Lagune cattle as a function of the body length

The weight prediction regression equations for Lagune cattle as a function of the body length were presented in Table 1. The logarithmic regression allowed estimating the weight with better precision in the Lagune cattle of both sexes. The polynomial regression showed lower coefficients of determination.

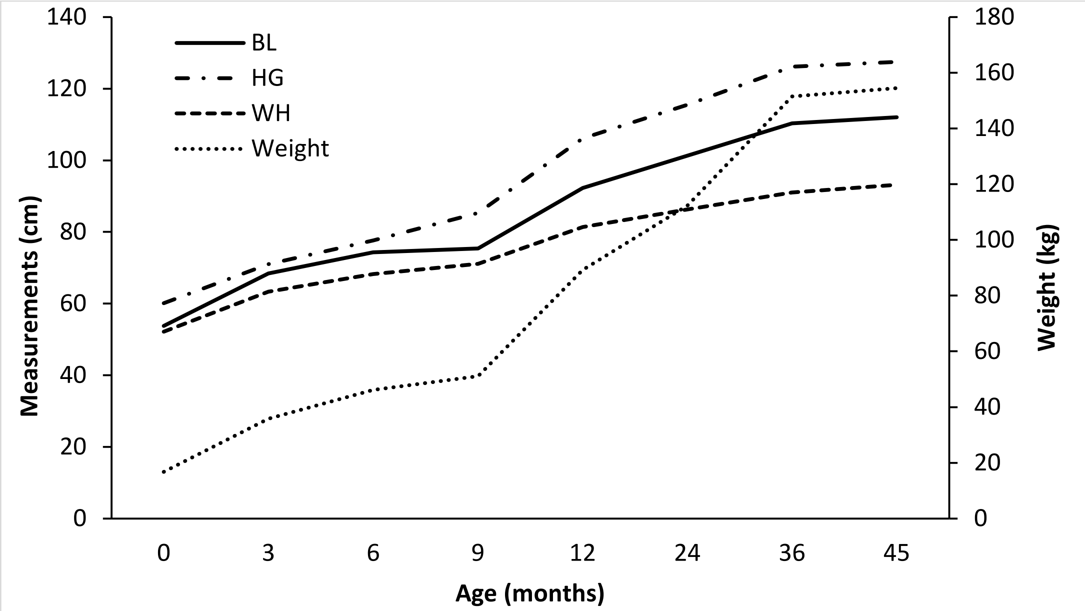

Fig-2: Evolution of linear measurements and weight in female Lagune cattle.

Table-1: Regression equations for Lagune cattle weight prediction as a function of the body length taken as the only independent variable.

Sex	Age (months)	Regression equations	R^2	S_y
Males	0-6	(A) $Y=20.13\ln(x) -2.04$	0.96	10.3
	6-12	(B) $Y= 23.46x^{0.3}$	0.93	15.0
	12-24	(C) $Y= -0.0008x^2 + 0.46x + 56.69$	0.76	15.4
	24-36	(D) $Y= 0.0033x^2 + 0.250x + 86.01$	0.67	13.4
	36-45	(E) $Y=42.19\ln(x) -100.3$	0.83	36.3
Females	0-6	(F) $Y= 17.53\ln(x) + 4.84$	0.93	6.1
	6-12	(G) $Y=23.25\ln(x) -14.4$	0.94	20.0
	12-24	(H) $Y= 29.71\ln(x) - 42.21$	0.84	14.9
	24-36	(I) $Y= -0.0025 x^2 + 0.79x + 44.41$	0.38	15.5
	36-45	(J) $Y= 27.11x^{0.28}$	0.38	12.2

Y: estimated weight (kg); x: body length (cm); R^2: coefficient of determination; Sy: residual standard deviation (kg).

In female's animals from 24 months of age, weight prediction models based on body length showed particularly low coefficients of determination, showing that this body measurement alone is not very accurate in predicting Females Lagune cattle having more than 24 months weight.

Prediction of the weight of the Lagune cattle as a function of the heart girth.

Of the different types of regressions tested to predict the weight of the Lagune cattle as a function of the HG (Table 2), only the polynomial regression showed the best coefficients of determination for the different age classes of the males.

In females, however, the highest coefficients of determination were obtained with logarithmic regression for the age groups 0-6, 6-12 and 12-24 months. Linear regression was more appropriate for females from 24 to 36 months, but with a relatively lower coefficient of determination. For females in the age range of 36 to 45 months, it was the polynomial regression that allowed a better prediction of weight (Table 2). The lowest coefficients of determination for the weight prediction equations in relation to HG were obtained in the age range of 24 to 36 months for Lagune cattle of both sexes.

Table-2: Regression equations for Lagune cattle weight prediction as a function of the heart girth taken as the only independent variable.

Sex	Age (months)	Regression equations	R^2	S_y
Males	0-6	(A) $Y= -0.00084z^2 + 1.38z + 39.43$	0.98	9.2
	6-12	(B) $Y= -0.0017z^2 + 0.74z + 53.89$	0.97	20.3
	12-24	(C) $Y= -0.002z^2 + 0.79z + 51.27$	0.96	16.6
	24-36	(D) $Y= -0.0016z^2 + 0.65z + 62.56$	0.84	12.3
	36-45	(E) $Y= -0.0001z^2 + 0.29z + 84.37$	0.94	35.1
Females	0-6	(F) $Y= 21.15\ln(z) + 1.28$	0.98	6.7
	6-12	(G) $Y= 28.40\ln(z) -23.08$	0.98	21.0
	12-24	(H) $Y= 34.65\ln(z) - 49.37$	0.95	15.5
	24-36	(I) $Y= 0.32z + 79.26$	0.73	12.9
	36-45	(J) $Y= -0.0004z^2 + 0.40z + 75.7$	0.80	12.6

Y: estimated weight (kg); z: heart girth (cm); R^2: coefficient of determination; Sy: residual standard deviation (kg).

Prediction of the weight of the Lagune cattle as a function of the heart girth

Predictive models of weight as a function of height at the withers of animals (Table 3) were more accurate in males than in females except females 6-12 months of age.

Table-3: Regression equations for Lagune cattle weight prediction as a function of the withers height girth taken as the only independent variable.

Sex	Age (months)	Regression equations	R^2	S_y
Males	0-6	(V) $Y= 15.35\ln(t) + 10.10$	0.94	6.4
	6-12	(W)$Y= -0.0016\ t^2 + 0.51t + 48.21$	0.89	17.5
	12-24	(A’)$Y= 26.86t^{0.24}$	0.75	17.5
	24-36	(B’)$Y= 0.17t + 65.57$	0.51	14.3
	36-45	(C’)$Y= -0.001t^2 + 0.49t + 43.60$	0.78	39.5
Females	0-6	(D’)$Y= 13.41\ln(t) + 14.76$	0.89	7.6
	6-12	(E’)$Y= 23.65t^{0.27}$	0.95	21.9
	12-24	(F’)$Y= 0.24t + 58.40$	0.76	22.6
	24-36	(G’)$Y= 0.0009t^2 - 0.048t + 80.25$	0.45	10.5
	36-45	(H’)$Y= 0.16t + 65.58$	0.45	12.1

Y: estimated weight (kg); t: withers height (cm); R^2: coefficient of determination; Sy: residual standard deviation (kg).

The prediction models developed were logarithmic in males as in females from 0 to 6 months of age with a higher coefficient of determination for the former. In age groups 6-12 months and 36-45 months, the polynomial regression yielded a better estimate of the weight of males with a relatively high coefficient of determination. In females of these same age groups, the regression was of power and linear types respectively in the age groups 6-12 months and 36-45 months.

Models of prediction of the Lagune cattle weight developed by the stepwise multiple regression

The Table 4 presented the weight prediction equations as a function of the body measurements developed by the stepwise multiple regression for Lagune cattle.

Table-4: Weight prediction models based on the three body measurements (BL. HG. WH) developed by the stepwise multiple regression for Lagune cattle

Sex	Age (months)	n	Prediction models	R^2	Cp
Males	0-6	102	(I’) $Y= -56.43 + 0.24x + 0.72z + 0.31t$	0.97	4.00
	6-12	165	(J’) $Y= -127.41 + 0.42x + 1.43z + 0.30t$	0.97	4.00
	12-24	100	(K’) $Y= -152.91 + 0.63x + 1.74z$	0.97	2.00
	24-36	62	(L’) $Y= -306.94 + 1.04x + 2.72z$	0.95	3.28
	36-45	82	(M’) $Y= -307.39 + 1.03x + 2.73z$	0.96	3.3
	Total	511	(N’) $Y= -77.29 - 0.07x + 1.47z + 0.18t$	0.95	4.00
Females	0-6	65	(O’) $Y= -38.81 + 0.18x + 0.96z - 0.21t$	0.96	4.00
	6-12	83	(P’) $Y= -96.80 + 0.68x + 1.13z$	0.97	3.77
	12-24	98	(Q’) $Y= -154.12 + 0.54x + 1.42z + 0.54t$	0.97	4.00
	24-36	95	(R’) $Y= -210.76 + 0.36x + 1.98z + 0.65t$	0.83	4.00
	36-45	62	(S’) $Y= -216.09 + 0.55x + 1.9z + 0.64t$	0.79	4.00
	Total	403	(U’) $Y= -91.31 + 1.74x + 1.77z - 1.99t$	0.94	4.00

Y: estimated weight (kg); x: body length (cm); z: heart girth (cm); t: withers height (cm); R^2: coefficient of determination; C_p: coefficient of Mallows.

These models showed coefficients of determination (R^2) ranging from 0.94 to 0.97 in males and from 0.79 to 0.97 in females. Mallows Cp coefficients also varied from 2.00 to 4.00 in males and from 3.77 to 4.00 in females. For the males Lagune cattle of the age groups 0-6 and 6-12 months, all three body measurements were used in the weight prediction models selected by the stepwise method. In the regression equations applicable to males Lagune cattle older than 12 months of age, only two body measurements (HG and BL) were used as explanatory variables. These latter equations had lower Cp Mallows coefficients, indicating better accuracy. On the other hand, in the case of female's animals, the weight prediction equation consisted only of two explanatory variables with a lower Mallows Cp coefficient for the 6-12 months age group. For the same animal category, weight prediction models developed for the 24-36 and 36-45 months age groups were characterized by relatively lower coefficients of determination. This showed that the weight prediction models developed in males had a better accuracy than the regression equations retained in females. The general, stepwise models for all age groups taken together included all three explanatory variables and were closed to the lower limit in both males and females.

Validation of weight prediction models for Lagune cattle.

Residual means and residual standard deviations of the differences between the real weights and the weights estimated using the regression equations developed for Lagune cattle of both sexes and different age classes were presented in Table 5.

Table-5: Differences between the real weights and the weights estimated by the different models developed.

Ages (months)	Males			Females		
	Differences	RM	S_y	Differences	RM	S_y
0 - 6	d1 = Pr – Pe(A)	25.4	13.3	d22 = Pr – Pe(F)	-55.9	0.7
	d2 = Pr – Pe(K)	61.9	10.4	d23 = Pr – Pe(P)	-69.5	4.3
	d3 = Pr – Pe(V)	-45.1	11.4	d24 = Pr – Pe(D')	-49.0	4.9
	d4 = Pr – Pe(I')	1.4	2.4	d25 = Pr – Pe(O')	-0.9	1.0
6 -12	d5 = Pr – Pe(B)	-34.3	14.8	d26 = Pr – Pe(G)	-27.2	24.6
	d6 = Pr – Pe(L)	-5.2	12.3	d27 = Pr – Pe(Q)	48.1	21.6
	d7 = Pr – Pe(W)	-36.2	10.2	d28 = Pr – Pe(E')	-14.1	20.8
	d8 = Pr – Pe(J')	0.7	2.0	d29 = Pr – Pe(P')	4.1	7.4
12 - 24	d9 = Pr – Pe(C)	-13.9	14.6	d30 = Pr – Pe(H)	-7.1	13.0
	d10 = Pr – Pe(M)	-52.2	10.5	d31 = Pr – Pe(R)	24.4	7.7
	d11 = Pr – Pe(A')	-36.2	10.3	d32 = Pr – Pe(F')	8.0	18.6
	d12 = Pr – Pe(K')	0.8	2.6	d33 = Pr – Pe(Q')	2.3	4.4
24 - 36	d13 = Pr – Pe(D)	-28.2	10.0	d34 = Pr – Pe(I)	16.9	12.0
	d14 = Pr – Pe(N)	1.3	6.2	d35 = Pr – Pe(S)	-0.8	10.8
	d15 = Pr – Pe(B')	-37.6	10.8	d36 = Pr – Pe(G')	-28.7	8.6
	d16 = Pr – Pe(L')	1.4	4.3	d37 = Pr – Pe(R')	1.7	2.6
36 – 45	d17 = Pr – Pe(E)	29.3	7.9	d38 = Pr – Pe(J)	31.5	10.6
	d18 = Pr – Pe(O)	7.0	7.4	d39 = Pr – Pe(U)	1.6	9.9
	d19 = Pr – Pe(C')	45.8	8.4	d40 = Pr – Pe(H')	52.3	11.2
	d20 = Pr – Pe(M')	0.5	3.3	d41 = Pr – Pe(S')	2.7	4.9
0 – 45	d21 = Pr – Pe(N')	2.6	5.3	d42 = Pr – Pe(U')	4.2	7.9

Di: Difference between real weight (Pr) and estimated weight (Pe) from equation i; RM: residual mean (kg); Sy: residual standard deviation (kg).

Of the four weight prediction models developed for Lagune cattle in the 0-6 month age bracket of both sexes, only the models obtained with the stepwise method and involving the three body measurements had the best accuracy (Low residual mean and residual standard deviation). This confirmed the observations made earlier concerning the low precision of weight prediction equations involving a single body measurement as an explanatory variable for animals of this age group.

In the age group of 6-12 months, the weight prediction equations developed by the stepwise method had the smallest residual means of difference between the real weights and the predicted weight of the animals at the level of both sexes. In males of this age group, the weight-prediction polynomial L-equation as a function of the heart girth, while slightly overestimating the weight, had an appreciable residual mean.

In the 12-24-month age group, the polynomial equations based on the three body measurements generated by the stepwise method showed the lowest residual means of the real and estimated weight differences, both in males and in females. At the level of the latter, the logarithmic equation H of prediction of the weight as a function of the body length, while overestimating the weight, had an appreciable residual mean.

From 24 months of age, two types of equations showed the lowest residual mean of the difference between the real and estimated weights of the animals of both sexes: the polynomial predictions of weight as a function of the heart girth and the models of prediction of the weight according to the three body measurements (BL. HG. WH) developed by stepwise regression. If residual means between real weights and weights estimated by these equations were close, the residual standard deviations of the models developed by stepwise regression were lower indicating better accuracy of the estimates.

DISCUSSION

The studies conducted in sub-Saharan Africa on the use of body measurements for estimating live weight of cattle were numerous (Table 6). They were unanimous that of all the body measurements of the animals, only four (heart girth. body length. withers height and spiral turn) were the most used for animal's weight estimation, because of their strong correlation with the animal's live weight. Although the spiral turn was interesting, its execution requires perfect restraint and manipulation by two operators with good knowledge of the morphology of the animals [10,15,16,22]. For these reasons, this measure was not identified in this study. At the level of all animals, the live weight was strongly correlated with the three types of measurements used. However, this correlation was less marked with the withers height, in accordance with the conclusions of some authors [16, 22, 23]. The measurements with the most accurate predictive value of live weight was the heart girth, as reported unanimously by different authors [10, 15, 16, 22, 23].

The study of the correlation between weight and body measurements showed a weaker relationship between weight and two measures (body length and withers height) in females compared to males, indicating an insidious effect of sex. It was established that the onset of sexual activity in females leads to a sudden slowdown in growth [16]. For the prediction models obtained by the stepwise method in the present study, only the most highly correlated measurements were retained in the prediction model. Apart from the coefficient of determination which indicated the accuracy of the prediction equation, the Mallows coefficient also complemented the level of accuracy. The more variables in the prediction model, the better R^2 can increase without improving accuracy [60]. The best equation was the one with the highest R^2 and the lowest Cp [61]. In this study, the prediction models obtained for each age group were more accurate in males than in females according to the observations of many authors [14, 19, 22]. This difference was related to the conformation of males, which differed from that of females [16-22]. At the same age, males had an anterior train that was heavier and bulkier than females in cattle in general and in the Borgu cattle in particular [22]. In general, the heart girth was the measurement that best estimated the weight of animals in males and females in this study. These results confirmed those of many authors who reported that the heat girth was the measurement that provided more accuracy on the predictive value of live weight [10, 15, 16, 22, 23, 24, 44]. After the heart girth, the withers height or the body length can be used in the prediction model. Adding one of the measurements to the heart girth can improve accuracy. From a strictly mathematical point of view, the total correlation coefficient of the multiple regression of y on x and z was always greater than or equal to that of the simple regression on one of the two variables [61]. This indicated that the information provided by two variables was richer than that provided by a single one [10]. In sum, the equation based solely on the heart girth had the advantage of being simple, requiring less work and allowing the establishment of directly applicable heart girth conversion tables.

In males from 12 months of age, polynomial regression with two variables was particularly accurate for the prediction of live weight of animals.

Table-6: Studies carried out in sub-Saharan Africa to estimate live weight of cattle using formulae derived from body measurements.

Country	Breed/ Type	Management
Benin	Lagune [14] ; Borgu [22-24]	Traditional [24]; Semi-intensive [14-22]
Cameroon	Kapsiki [23] ; Zebu Peul (Adamaoua) [25]	Traditional [23] ; Semi-intensive [25]
Congo	Alur. Bahima (Ankolé) [26]	Traditional [26]
Côte-d'Ivoire	Baoulé. N'dama. Baoulé x N'dama [15]	Traditional and Semi-intensive [15]
Ethiopia	Horro. Barca. Boran and crosses [27] ; Abyssinian short-horned zebu [28]	Semi-intensive [27] ; Traditional [28]
Gambia	N'dama [29]	Traditional [29]
Kenya	Est African short-horned zebu and crosses [30-31-32]	Ranching [30] ; Traditional [31-32]
Malawi	Malawi zebu [33] ; Malawi zebu x Friesian [34]	Semi-intensive (research station) [33-34]
Mali	Zebu Maure. zebu Peul [35]	Ranching [35]

Niger	Zebu Azawak [19]	Semi-intensive [19]
Nigeria	White Fulani [36-37] ; Gudali. N'dama. Bunaji [38-39-40] ; Boran. Muturu (Lagune). N'dama [41]	Semi-intensive (research station) [36-37-38-39-40-41]
Rwanda	Ankolé [42]	Semi-intensive [42]
Senegal	Djakoré [16] ; Gobra [43] ; N'dama [44]	Traditional [16-43] ; Semi-intensive (research station) [44]
Sierra Leone	N'Dama [45]	Traditional [45]
South Africa	Afrikander. Angus. Hereford. Sussex [46] ; Ayrshire. Guernsey. Jersay [47] ; Nguni [48]	Intensive (research station) [46-47] ; Traditional [48]
Sudan	N'dama [49] ; Kenana [50-51] ; Baggara zebu [52]	Semi-intensive (research station) [49-50] ; Traditional [51-52]
Swaziland	Nguni [53]	Traditional [53]
Tanzania	Tanganyika zebu et Hereford crosses [54] ; Tanzania Shorthorn Zebu [55]	Semi-intensive (research station) [54] ; Traditional [55]
Togo	Somba [56]	Traditional [56]
Uganda	Teso zebu (Nkedi) [57-58] ; Ankolé [59]	Semi-intensive (research station) [57-58-59]

The heart girth and the body length (together) could translate an aspect of volume and a rough representation of animals in the form of a cylinder. This cylindrical form would be more pronounced in males than in females. A close connection could be imagined between this volume and the weight. In practice, the measurement of the body length was relatively easy [16-19]. The use of the third variable (withers height) in weight prediction models in Lagune females older than 12 months could be explained by the lack of accuracy related to their (often unknown) physiological state, which may modify significantly the nature of the observed connections [16-22].

CONCLUSION

This study established that the heart girth was the body measure that best estimated the weight of the Lagune cattle. The precision of the estimate improved when the body length was associated with it in a polynomial equation with two independent variables and was higher in males than females. In the latter, the combination of the third body measure (withers height) improved the accuracy of the estimate. The polynomial regression equations of the predicted weight as a function of the heart girth developed in Lagune cattle of both sexes aged 24 to 45 months can be used to establish a table of conversion of the heart girth by weight. These formulas were applicable to Lagune cattle and can be used with adequate precision by farmers who, under field conditions, generally do not have animal weighing devices to monitor weight growth, correct dosage of medicines and exact weight selling of animals.

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