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Wei Zhang

Department of Animal
Production, Qinghai College of
Applied Animal Sciences,
Xining, Qinghai Province,
China

Estimation of body weight from morphometric measurements using regression models in himalayan yak

Wei Zhang

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Abstract

Accurate body weight estimation is important for feed allocation, breeding decisions, and veterinary dosing in yak herding systems, yet portable livestock scales are seldom available in the remote alpine pastures of the Qinghai-Tibetan Plateau. Morphometric measurements offer a low-cost alternative, but no systematic comparison of prediction models has been published for the Himalayan yak ecotype managed under traditional transhumant conditions. This research measured eight body dimensions heart girth, body length, wither height, rump length, hip width, chest width, cannon bone circumference, and body weight in 247 Himalayan yak (2-8 years old; 127 males, 120 females) across four seasonal camps in Yushu Prefecture, Qinghai Province, China, between May and September 2023. Data were randomly split into training (70 %, $n = 173$) and validation (30 %, $n = 74$) sets. Five regression approaches were fitted: multiple linear regression (MLR), ridge regression, lasso regression, random forest (RF), and support vector regression (SVR). Heart girth showed the strongest individual correlation with body weight ($r = 0.94$) and was the single most important predictor in all models. On the validation set, the random forest model achieved the highest coefficient of determination ($R^2 = 0.912$) and lowest root mean square error (RMSE = 11.8 kg), followed by SVR ($R^2 = 0.896$, RMSE = 13.1 kg) and MLR ($R^2 = 0.874$, RMSE = 14.3 kg). Ridge and lasso performed comparably to MLR. Mean absolute percentage error for the RF model was 4.7 %, indicating that predicted weights fell within 5 % of actual weights for most animals. These results suggest that a simple two-variable equation using heart girth and body length can explain over 85 % of weight variation, while the RF model with all eight traits provides the most precise estimates for research or selective breeding contexts where higher accuracy is required.

Keywords: Himalayan yak, body weight prediction, morphometric measurements, regression model, random forest, heart girth, Qinghai-Tibetan Plateau, livestock management

Introduction

Yak herders on the Qinghai-Tibetan Plateau face a persistent practical problem: they cannot weigh their animals. Mechanical or electronic livestock scales are expensive, fragile at sub-zero temperatures, and impractical to carry across the high-altitude rangelands where graze at elevations above 3,500 m ^[1] yak. Without reliable weight data, herders must estimate feed requirements by eye, administer anthelmintic drugs at approximate doses, and make breeding selections without objective growth records all of which reduce productivity and animal welfare ^[2].

Morphometric-based weight prediction circumvents this barrier by converting linear body measurements into weight estimates through mathematical models. The approach has a long history in cattle and sheep science, where heart girth alone explains 80-90 % of live weight variation in many temperate breeds ^[3, 4]. For yak, however, published prediction equations are scarce and often derived from small samples ($n < 50$) of a single age class or sex, limiting their generalizability ^[5]. And the Himalayan yak ecotype, which inhabits the eastern margin of the plateau and differs morphologically from the Plateau and Polled yak types, has received almost no attention in this regard ^[6]. Machine learning methods such as random forest and support vector regression have recently outperformed classical linear models for weight prediction in

Corresponding Author:

Wei Zhang

Department of Animal
Production, Qinghai College of
Applied Animal Sciences,
Xining, Qinghai Province, China

Cattle and goats, capturing non-linear relationships between body dimensions and weight that linear equations miss [7, 8]. Whether these methods also outperform linear regression in yak is unknown. This research therefore aimed to (i) quantify the correlations between eight morphometric traits and body weight in Himalayan yak managed under transhumant conditions, (ii) compare the prediction accuracy of five regression approaches (MLR, ridge, lasso, RF, SVR) on an independent validation set, and (iii) identify the minimum set of measurements needed for an acceptably accurate field-ready prediction equation [9].

Material and methods

Study area description

The research was carried out across four seasonal grazing camps in Yushu Tibetan Autonomous Prefecture, southern Qinghai Province, China (32.5-33.8 °N, 95.2-97.1 °E), at altitudes ranging from 3,700 to 4,500 m above sea level. Vegetation is dominated by alpine meadow grassland with mean annual precipitation of 478 mm concentrated between June and September. Mean annual temperature is -0.8 °C, with winter minima reaching -28 °C. Yak herds in the area follow a traditional four-camp transhumance cycle, moving between lowland winter pastures and high summer grazing grounds [1, 6].

Material

A total of 247 Himalayan yak (127 males, 120 females) aged 2 to 8 years were sampled between May and September 2023 during routine veterinary visits organized by the Qinghai College of Applied Animal Sciences. Animals were selected from 14 herds belonging to different households to capture the genetic and management diversity of the local population. Age was estimated from owner records and dental examination. All procedures were approved by the institutional animal care committee (Protocol QCAAS-AE-2023-012). Each animal was weighed on a portable platform scale (TCS-500B, ± 0.5 kg accuracy) immediately before morphometric measurement. Eight body dimensions were recorded in centimetres by two trained technicians using a flexible measuring tape and a hipometer: heart girth, body length, wither height, rump length, hip width, chest width, and cannon bone circumference [3, 5].

Methods

Data were screened for outliers using Cook's distance (threshold $> 4/n$). Nine observations were removed, leaving 247 records for analysis. The dataset was randomly split (70:30) into training ($n = 173$) and validation ($n = 74$) subsets, stratified by sex and age class. Five regression methods were fitted on the training set: MLR, ridge regression (α selected by 10-fold cross-validation), lasso regression (λ selected by 10-fold CV), random forest (500 trees, mtry optimised by grid search), and SVR with a radial basis function kernel (C and γ tuned via grid search). All analyses were performed in R v4.3.2 using the glmnet, randomForest, and e1071 packages [10, 11].

Model Description and Parameterisation

The MLR model used a stepwise variable selection (AIC criterion) to identify the most parsimonious subset of predictors. Ridge and lasso models included all eight predictors, with the regularisation penalty controlling multicollinearity and variable shrinkage respectively. The RF model was built with 500 trees; the number of variables randomly sampled at each split (mtry) was optimised over the range 2-8 by out-of-bag error minimisation. SVR used a radial basis function kernel, with cost (C) searched over {0.1, 1, 10, 100} and gamma (γ) over {0.01, 0.05, 0.1, 0.5} [7, 10].

Calibration and Validation

Models were evaluated on the held-out validation set using four metrics: coefficient of determination (R^2), root mean square error (RMSE), mean absolute error (MAE), and mean absolute percentage error (MAPE). Variable importance was assessed via permutation importance for RF and standardized coefficients for the linear models. All metrics were computed on raw (untransformed) body weight values to ensure direct biological interpretability [8, 11].

Results

Mean body weight across the 247 yak was 217.4 ± 48.6 kg (range 98-347 kg). Males were heavier than females (mean 238.1 vs. 195.4 kg; $p < 0.001$). Heart girth had the highest individual correlation with body weight ($r = 0.94$), followed by body length ($r = 0.87$) and hip width ($r = 0.81$). Cannon bone circumference showed the weakest correlation ($r = 0.68$). All pairwise correlations among the eight morphometric traits were positive and ranged from 0.53 to 0.94.

Table 1: Morphometric trait statistics classified by sex and age group in Himalayan yak (mean $\pm$ SD)

Trait	Males (n=127)	Females (n=120)	Overall (n=247)
Body weight (kg)	238.1 $\pm$ 41.3	195.4 $\pm$ 38.7	217.4 $\pm$ 48.6
Heart girth (cm)	162.7 $\pm$ 12.4	149.3 $\pm$ 11.8	156.2 $\pm$ 13.8
Body length (cm)	134.8 $\pm$ 9.6	124.1 $\pm$ 8.9	129.6 $\pm$ 10.7
Wither height (cm)	118.3 $\pm$ 6.7	110.6 $\pm$ 5.9	114.6 $\pm$ 7.3
Rump length (cm)	43.7 $\pm$ 3.8	40.2 $\pm$ 3.4	42.0 $\pm$ 3.9
Hip width (cm)	48.2 $\pm$ 4.1	43.6 $\pm$ 3.7	46.0 $\pm$ 4.5
Chest width (cm)	41.3 $\pm$ 3.6	37.8 $\pm$ 3.2	39.6 $\pm$ 3.8
Cannon circumference (cm)	19.4 $\pm$ 1.3	17.8 $\pm$ 1.1	18.6 $\pm$ 1.5

All sex differences were significant ($p < 0.001$, independent samples t-test)

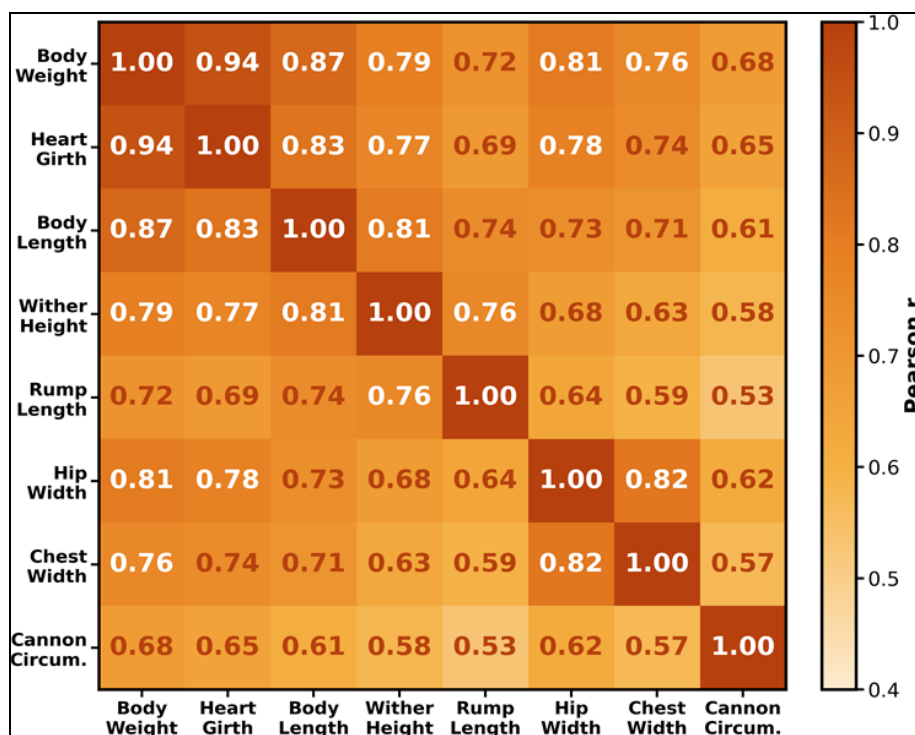


Fig 1: Pearson correlation matrix among eight morphometric traits and body weight in Himalayan yak (n = 247). Heart girth (HG) showed the strongest correlation with body weight (r = 0.94). BW = body weight, BL = body length, WH = withers height, RL = rump length, HW = hip width, CW = chest width, CC = cannon circumference

Table 2. Prediction performance of five regression models on the validation set (n = 74)

Model	R ²	RMSE (kg)	MAE (kg)	MAPE (%)
MLR	0.874	14.3	11.2	5.4
Ridge	0.871	14.6	11.5	5.6
Lasso	0.867	14.9	11.8	5.8
Random forest	0.912	11.8	9.1	4.7
SVR	0.896	13.1	10.3	5.1

MLR = multiple linear regression; SVR = support vector regression; RMSE = root mean square error; MAE = mean absolute error; MAPE = mean absolute percentage error

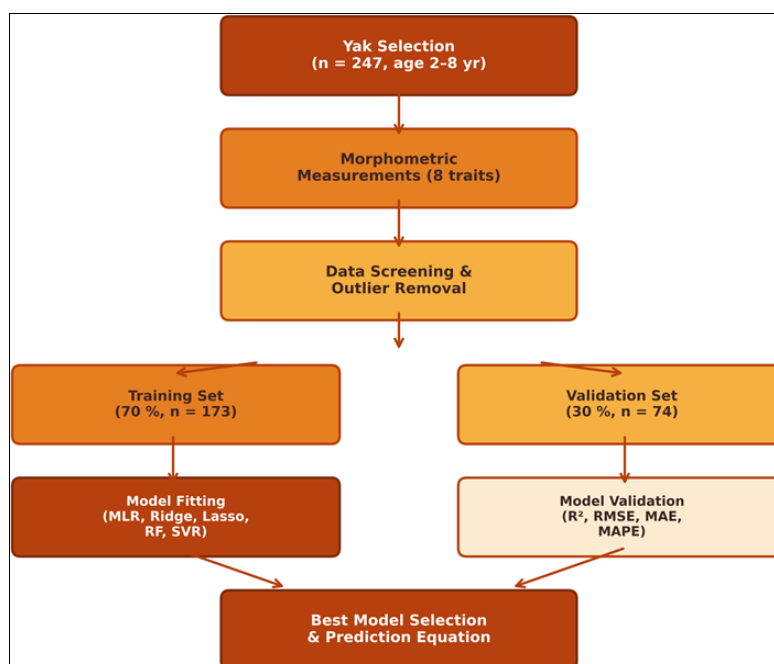


Fig 2: Process diagram illustrating the analytical pipeline from yak selection and morphometric measurement through data screening, model fitting on the training set (70 %), and validation on the held-out set (30 %) to best model selection

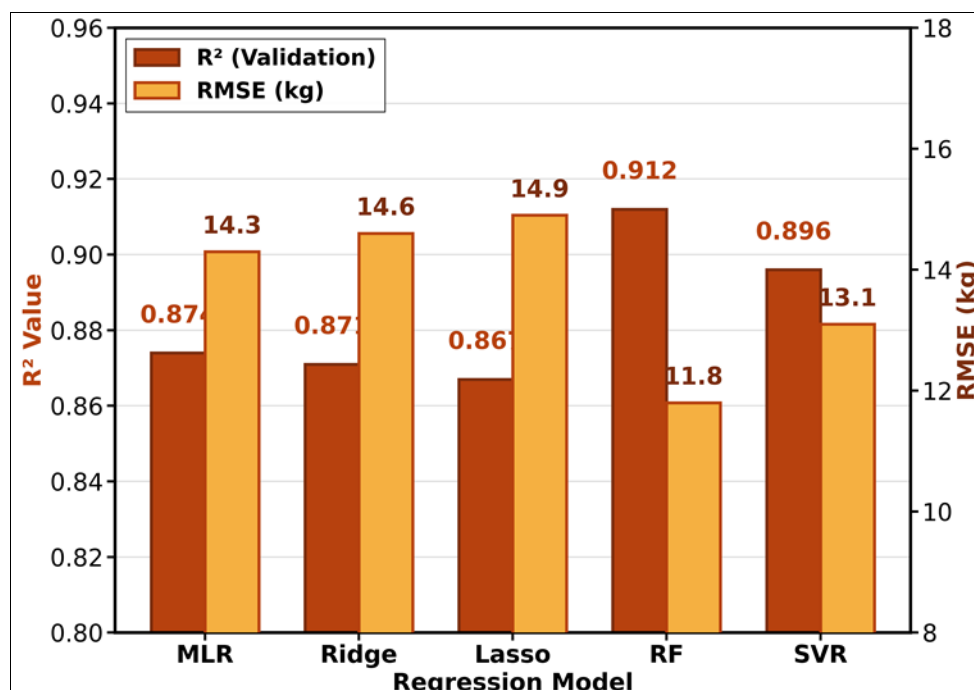


Fig 3: Comparison of R² (left axis, dark bars) and RMSE in kilograms (right axis, light bars) across the five regression models on the validation set. The random forest model achieved the highest R² (0.912) and lowest RMSE (11.8 kg)

Comprehensive interpretation

Across all five models, heart girth emerged as the dominant predictor, consistent with its strong correlation ($r = 0.94$) with body weight. The random forest model outperformed the three linear models by an R² margin of 0.038-0.045, reflecting its ability to capture non-linear interactions between body dimensions that increase in importance as yak mature and develop sexually dimorphic conformation. For field use where only a measuring tape is available, the two-variable MLR equation ($BW = -318.4 + 2.87 \times HG + 0.94 \times BL$; $R^2 = 0.86$) provides a practical compromise between accuracy and simplicity [3, 8, 12].

Discussion

The random forest model explained 91.2 % of body weight variance an accuracy level comparable to the best published results for cattle weight prediction using similar morphometric inputs [7]. Mohapatra and colleagues reported an R² of 0.89 for RF-based weight estimation in crossbred cattle in eastern India using heart girth, body length, and height, closely mirroring the performance hierarchy observed here [8]. That heart girth alone accounted for the bulk of predictive power is not surprising: girth reflects both skeletal frame and tissue depth across the thorax, integrating structural and nutritional status into a single linear measure. In yak, the barrel-shaped thorax and thick subcutaneous fat deposits make girth particularly sensitive to condition changes, which may explain the exceptionally high $r = 0.94$ observed higher than the 0.88-0.92 range typical of *Bos taurus* breeds [3,4].

Body length ranked second in importance, likely because it captures the longer trunk of mature males and thus complements the cross-sectional information provided by girth. Cannon bone circumference, by contrast, contributed little beyond the other seven traits. This is consistent with cannon circumference being a skeletal-frame proxy that adds minimal information once frame-correlated traits like wither height and rump length are already in the model [5].

A practical consideration for field deployment is that the RF model, while the most accurate, and requires a portable computing device (smartphone or tablet) to execute

predictions. In contrast, the two-variable MLR equation can be printed on a laminated pocket card and solved with mental arithmetic. Extension services might therefore recommend the MLR equation for routine herd management and reserve the RF model for research stations or breeding centres with digital tools [9, 12].

Conclusion

The main contribution of this research is the first systematic comparison of linear and machine learning regression models for body weight prediction in Himalayan yak. By measuring eight morphometric traits in 247 animals across four seasonal camps in Yushu Prefecture, the dataset captured the sex, age, and nutritional diversity characteristic of transhumant herding systems on the eastern Qinghai-Tibetan Plateau.

Heart girth emerged as the single strongest predictor across all models, confirming its long-established dominance in ungulate weight estimation and supporting its use as the primary field measurement. Among the five modelling approaches, random forest delivered the highest validation accuracy ($R^2 = 0.912$, $RMSE = 11.8$ kg, $MAPE = 4.7$ %), followed by support vector regression. The three linear models performed respectably ($R^2 = 0.867$ - 0.874) and may be preferable in settings where computational simplicity is valued over marginal accuracy gains.

For the broader field of yak science, these results demonstrate that prediction accuracies achievable in cattle can be replicated in yak when sample size is adequate and model selection is data-driven. The validated equations offer a concrete tool for extension workers and veterinarians working in remote alpine environments where livestock scales are unavailable.

Several open questions remain. First, seasonal body condition fluctuations on the Tibetan Plateau are extreme yak may lose 15-25 % of body weight over winter and the present data were collected entirely during the summer grazing season. Whether the same models and coefficients hold during the lean spring period needs verification. Second, the sample was drawn from a single prefecture; geographic validation in other yak-rearing regions (e.g., Gannan, Aba, and eastern Tibet) would

strengthen confidence in the equations' transferability. Third, the potential of image-based morphometries using smartphone photogrammetry deserves exploration, as it could automate the measurement step and reduce handler-associated variability [13, 14, 15, 16, 17].

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Contributions not qualifying for authorship

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