Modelling Growth from Weaning to Maturity in Beef Cattle Breeds

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Summary

To better understand growth trajectory and maturity differences between beef breeds, three models – Brody, spline, and quadratic – were fit to cow growth data, and resulting parameter estimates were evaluated for three breed categories – British, continental, and Brahman-influenced. The data were weight-age pairings from 4,721 cows from the U.S. Meat Animal Research Center Germplasm Evaluation Program. Parameters estimated were mature weight and maturing rate () from a Brody function, intercept for left and right segments and slope of the right segment of a linear spline, and (intercept; coinciding with weaning weight), (linear coefficient), and (quadratic coefficient) of a quadratic regression. Estimates of the coefficients from the fit of the quadratic regression and the spline function were both used to predict mature weight at six years old. All estimates were near 0.003 day^{-1}. Mature weight estimates ranged from 594.4 to 746.0 kg. Direct heterotic effect of mature weight was estimated as 14.1 (± 2.8) kg. Weaning weight estimates ranged from 256.7 to 313.8 kg. From the fit of the three functions, British and Brahman-influenced breeds had similar weights at maturity while continental breeds were lightest. Conversely, at weaning, continental breeds were heaviest while British and Brahman-influenced breeds tended to be lighter and similar in weight. However, at neither maturity nor weaning did weights differ significantly among the breed categories. In future analyses, variance components will be estimated for mature weight, as well as individual breed and maternal heterotic effects.

Keywords: beef cattle, mature weight, Brody curve, spline function

Introduction

Cow mature weight has been reported to be increasing in the United States since the 1970's (e.g., Dib *et al.*, 2010). Heavier cattle require greater feed input, and therefore a greater net cost to maintain. DiCostanzo *et al.* (1990) found that for cows of similar fatness, heavier cows required more energy intake, and Jenkins & Ferrell (1984) estimated approximately 50% of total feed energy in beef production is used for cow maintenance. Individual production systems may not be able to remain profitable while supporting the increased intake of heavier cows (Beck *et al.*, 2016). While producers may wish to consider making use of various breeds to control mature weight as appropriate for their individual operations, differences in mature weights among U.S. beef breeds are not currently available. Consequently, the goal of this study was to estimate mature weights in an array of beef breeds managed under similar conditions using three different growth models – Brody, spline, and quadratic regression – as a first step toward enabling more informed breed utilization.

Materials and Methods

Animals

Data were from cows from the U.S. Meat Animal Research Center (USMARC) Germplasm Evaluation program. Through eight cycles of mating and, since 2007, from continuous sampling of industry bulls, a crossbred population has been established and maintained at USMARC. Data for this project were from Cycle VII (Wheeler *et al.*, 2005; Cushman *et al.*, 2007) and from the current sampling of industry bulls (Kuehn & Thallman, 2016). Beginning with the 2007 calving, bulls from five to seven breeds have been mated to Angus, Hereford, and MARC III cows; the matings of the Angus and Hereford bulls were designed to provide a benchmark for comparison. All cows were bred annually and culled after failing to breed twice or after developing substantial impairments to productivity.

Cycle VII cows (n=2,234) were born in spring seasons between 1999 and 2008, reached a maximum of 14 years of age, and represented the following breed types: Angus, Hereford, Red Angus, Charolais, Gelbvieh, Limousin, Simmental, and MARC III (one-quarter each Angus, Hereford, Pinzgauer, and Red Poll). Cows in continuous sampling (n=3,048) were born in spring and fall seasons between 2007 and 2014 and represent the following breed types: Angus, Hereford, Red Angus, Shorthorn, Beefmaster, Brahman, Brangus, Santa Gertrudis, Braunvieh, Charolais, Chiangus, Gelbvieh, Limousin, Maine Anjou, Salers, Simmental, Tarentaise, MARC II (one-quarter each Simmental, Hereford, Angus, and Gelbvieh), and MARC III.

Breed types were then classified as one of four groups: British (Angus, Hereford, Red Angus, Shorthorn, and Chiangus), continental (Braunvieh, Charolais, Gelbvieh, Limousin, Maine Anjou, Salers, Tarentaise, and Simmental), Brahman-influenced (Beefmaster, Brahman, Brangus, and Santa Gertrudis), and commercial dams (Angus, Hereford, Simmental, Charolais, MARC II, and MARC III). Breed type effects for commercial dams were fit in the analysis, but not reported, because they are less relevant to industry populations and subject to misinterpretation.

Data

Animals with records that did not go beyond three years of age, or with missing pedigree data, were removed. Weights collected beyond six years of age also were removed. Animal records were truncated if they contained gaps between subsequent records greater than two years, or if the cow had been placed on a feed restricted diet.

Breed fraction and retained heterosis estimates were calculated based on pedigree information. For breed fraction calculation, all breeds, including composites, were considered their own group. For example, a Chiangus x Angus cow would have fractions of 0.5 Chiangus and 0.5 Angus. Heterosis fractions were assigned based on nominal breed fractions. For example, the same Chiangus x Angus cow would have fractions of 0.75 Angus and 0.25 Chianina. Expected heterozygosity was calculated for each individual as one minus the proportion of the same breed from the sire and dam.

Statistical Analysis

Three models – a Brody function, a spline function, and a quadratic regression – were fitted. The Brody function was of the form:

(1)

where (kg) was the weight at age (day), was the time origin of the curve (= 180 days), was mature weight (kg), and (per day) was an exponential growth (maturing) constant (Taylor, 1965). Weights were scaled by subtracting an initial weight of 214.3 kg, which was the average weight of all records at 180 days of age (near weaning). Estimates for and were calculated for each animal via the nls function (nonlinear least squares) in R (R Core Team, 2017). Starting estimates of were obtained for each animal by averaging the scaled weights on each animal's last six records. A starting estimate of was obtained for each animal by algebraically re-arranging the Brody function to solve for *k*.

A linear spline with one interior knot was fitted using the segmented package in R (Muggeo, 2008). For each animal, the function was fitted by applying the function to a linear model relating the animal's scaled weights to its corresponding scaled ages. The starting value for the interior knot was set at 750 days of age, roughly coinciding with the age at which growth rates were anticipated to substantially slow. The slopes and intercepts from the fit of the function were obtained. The right-hand slope and intercept were used to predict the animal's weight at six years of age (maturity).

A quadratic model was also fitted using the lm function in R (R Core Team, 2017). Parks (1982) claimed that polynomial functions of sufficient order were appropriate for describing growth through maturity providing they were not used for extrapolation. Animals' parameter estimates from the fit of the quadratic regression were used to predict weight at six years of age (maturity).

For each model parameter estimated, a linear model without an intercept was then fit using the lm function in R (R Core Team, 2017) in which the observed parameter vector was a function of breed type fractions (e.g., proportion Angus, Santa Gertrudis, etc.), contemporary group (year-season of birth and whether a cow had moved to another contemporary group), and direct heterosis. Animals with estimated mature weights either greater or lesser than 2.2 interquartile range units from the mean for any function fitted were excluded. After editing, parameter estimates on 4,721 cows with 116,394 weight records were retained.

Mature and weaning weights, and other parameter values, were summarized by breed categories: British, continental, and Brahman-influenced. Weighted means were obtained by accounting for the number of records on each breed type contributing to each category.

Results

Table 1 shows the Brody parameter estimates calculated for each breed and their standard errors. Estimated were re-expressed by adding the average weight at 180 days (214.3 kg). Mature weights were similar for the three breed categories, although on average British and Brahman-influenced cattle were slightly heavier than continental cattle. Maturing constants were similar across breeds.

In Table 2 parameter estimates for the left intercept (weaning weight), right intercept and right slope obtained from the fit of the spline function are provided. Mature weights were estimated by using the values for the right slope and right intercept, and solving the linear equation at 6 years of age. These weights also were re-expressed by adding the average weaning weight (214.3 kg). Although not significantly different, British and Brahman-influenced breeds tended toward lighter weaning weights while the continental breeds were heavier. Conversely, Brahman-influenced and British breeds again were estimated to be heavier at maturity while continental breeds slightly lighter.

In Table 3, the coefficients obtained from the fit of the quadratic regression are provided by breed category. All linear coefficients were near 0.6 kg/day, and all quadratic coefficients were near -0.0002 kg/day^2. Weaning weight (β_0) was re-expressed by adding the average weight at 180 days. Weights at maturity were obtained by solving the quadratic function at 6 years of age. As with the fit of the other functions, weights at weaning and maturity were very similar. Still, continental breeds were again estimated to be slightly heavier than British and Brahman-influenced breeds at weaning but slightly lighter at maturity.

Discussion

Mature weight estimates, calculated as Brody's A or from coefficient values obtained from the fit of the quadratic regression and spline curve, ranged from 594.4 to 746.0 kg. Within each function, the average mature weight for the three breed categories were similar. However, continental cattle were always slightly lighter at maturity than British and Brahman-influenced breeds. Mature weights obtained using the spline function were heaviest since its fit was not asymptotic. Estimates of Brody's maturing constant were all near 0.003 days^{-1}. Our values of and A were similar to but slightly higher than those found by Kaps *et al.* (1999) and DeNise & Brinks (1985). This difference may reflect the genetic trend toward heavier cattle

Weaning weights estimated from the intercept of the quadratic regression and the left intercept of the spline function were between 256.7 and 313.8 kg, which were near but slightly higher than those reported by Kaps *et al.* (1999). Weaning weights estimated from the intercept of quadratic regression were about 55 kg heavier than that from the spline for each breed category. Both models estimated continental breeds to be slightly heavier at weaning, although all three breed types were similar in weaning weight.

In future analyses of these data, variance component estimates for mature weight will be obtained along with individual breed and maternal heterotic effects.

Table 1. Average Brody parameter estimates.[1]

	A (kg)		k (day^{-1})	
Breed Type	Mean	SE	Mean	SE
British	686.4	21.2	0.0034	0.00021
Continental	672.4	21.3	0.0035	0.00021
Brahman-Influenced	686.0	23.1	0.0033	0.00023
Direct Heterosis	14.1	2.8	0.00013	0.000028

[1] A = Mature Weight, kg; k = Brody's maturing interval, days^{-1}

Table 2. Average spline function parameters.[1]

	Left Intercept (kg)		Right Intercept (kg)		Right Slope (kg/day)		Pred. Mat. Wt. (kg)	
Breed Type	Mean	SE	Mean	SE	Mean	SE	Mean	SE
British	256.7	9.5	556.1	27.7	0.094	0.017	746.0	23.4
Continental	264.4	9.5	566.6	27.8	0.078	0.018	723.8	23.5
Brahman-Influenced	258.9	10.4	557.5	30.2	0.090	0.019	739.0	25.5
Direct Heterosis	11.9	1.3	10.9	3.7	0.0056	0.0023	22.2	3.1

[1] Left intercept was at 180 days of age thus approximates weaning weight; right intercept and right slope were used to estimate weight at 6 years of age (maturity).

Table 3. Average parameter estimates for the quadratic function. [1]

	β_0 (kg)		β_1 (kg/day)		β_2 (kg/day)^2		Pred. Mat. Wt. (kg)	
Breed Type	Mean	SE	Mean	SE	Mean	SE	Mean	SE
British	314.3	11.2	0.60	0.031	-2.3×10^{-4}	1.8×10^{-5}	600.8	30.4
Continental	318.3	11.2	0.58	0.031	-2.2×10^{-4}	1.8×10^{-5}	594.4	30.5
Brahman-Influenced	313.8	12.2	0.58	0.034	-2.1×10^{-4}	1.9×10^{-5}	609.0	33.1
Direct Heterosis	11.4	1.5	0.015	0.0041	-5.9×10^{-6}	2.4×10^{-6}	17.5	4.1

[1] β_0 = Intercept (weaning weight, kg); β_1 = Linear coefficient (kg/day); β_2 = Quadratic coefficient (kg/day^2); weights at 6 years of age (maturity) were estimated from the parameter estimates from the quadratic function.

List of References

Beck, P. A., C. B. Stewart, M. S. Gadberry, M. Haque & J. Biermacher, 2016. Effect of mature body weight and stocking rate on cow and calf performance, cow herd efficiency, and economics in the southeastern United States. J. Anim. Sci. 94:1689-1702.

Cushman, R. A., M. F. Allan, R. M. Thallman & L. V. Cudiff. 2007. Characterization of biological types of cattle (Cycle VII): influence of postpartum interval and estrous cycle length on fertility. J. Anim. Sci. 85:2156-2162.

DeNise, R. S. K. & J. S. Brinks, 1985. Genetic and environmental aspects of the growth curve parameters in beef cows. J. Anim. Sci. 61(6):1431-1440.

Dib, M. G., L. D. Van Vleck & M. L. Spangler, 2010. Genetic analysis of mature size in American Angus cattle. 2010 Nebraska Beef Cattle Report. 23-30.

DiCostanzo, A., J. C. Meiske, S. D. Plegge, T. M. Peters & R. D. Goodrich, 1990. Within-herd variation in energy utilization for maintenance and gain in beef cows. J. Anim. Sci. 68:2156-2165.

Jenkins, T. G. & C. L. Ferrell, 1983. Nutrient requirements to maintain weight of mature, nonlactating, nonpregnant cows of four diverse breed types. J. Anim. Sci. 54(4):761-770.

Kaps, M., W. O. Herring & W. R. Lambertson, 1999. Genetic and environmental parameters for mature weight in Angus cattle. J. Anim. Sci. 77:569-574.

Kuehn, L. A. & R. M. Thallman, 2016. Across-breed EPD tables for the year 2016 adjusted to breed differences for birth year of 2014. 2016 Beef Improvement Federation annual meeting & symposium. 127-154.

Muggeo, V. M. R. 2008. Segmented: An R package to fit regression models with broken-line relationships. R News, 8/1. 20-25. URL https://cran.r-project.org/doc/Rnews/

Parks, J. R., 1982. A theory of feeding and growth of animals. Springer-Verlag Berlin Heidelberg, Germany. 322pp.

R Core Team, 2017. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Taylor, St. C. S., 1965. A relation between mature weight and time taken to mature in mammals. Anim. Sci. 7:203-220.

Wheeler, T. L., L. V. Cundiff, S. D. Shackelford. & M. Koohmaraie. 2005. Characterization of biological types of cattle (Cycle VII): carcass, yield, and longissimus palatability traits. J. Anim. Sci. 83:196-207.