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Linear and nonlinear mixed model analyses of growth performance of commercial U.S. dairy buck kids

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ABSTRACT

The objectives of this research were: (1) to describe the growth of crossbred, intact, dairy buck kids from shortly after weaning to slaughter weight and (2) to determine whether raising them can be profitable. The kids in this study were purchased from three commercial dairy goat farms and were fed to slaughter weight in two separate environments. Individual kid body weight (BW) and pen feed disappearance was recorded. Both a linear mixed model and a nonlinear Gompertz mixed model were implemented to describe BW over the time of the feeding trial. The fits of the models were compared by −2 log likelihood, Akaike information criterion, and Bayesian information criterion. All fit statistics favored the nonlinear model, though upon visual inspection, growth was near linear. Although groups of kids were sold at varying weights and for different prices, revenues over kid purchase price and feed costs were positive. Feeding cull dairy kids can be profitable under many production scenarios.

1. Introduction

Dairy goat numbers have grown in the United States in recent years with a 29% increase from 2005 to 2015 (from 283,500 to 365,000 head). Wisconsin reported a 2015 estimated inventory of 44,000 head, the most of any state. Of the 250,000 dairy kids born throughout the U.S. in 2014, an estimated 69,000 were kept as replacement breeding stock leaving the remainder as potential market animals (NASS, 2015). However, because of the costs associated with raising kids to market weight, many producers see little economic value in cull buck and doe kids, and on-farm euthanasia shortly after birth is common.

Growth rate of these non-replacement kids is a major factor in determining their economic value. The body weight (BW) of an animal as a function of time is one of several ways to quantify growth. If BW is measured throughout an animal's lifetime, it can be described in three phases: early exponential growth, followed by a period of linear growth, and ending in diminishing growth when the animal approaches its mature weight (Karkach, 2006). These three phases combine to form a nonlinear, sigmoidal growth curve. Many mathematical functions have been developed or adapted to describe the pattern of animal growth.

One of the benefits of fitting a mathematical function to animal BW records over time is that, oftentimes, the parameters of the function have direct biological meaning. Some characteristics of growth that are important to meat animal production (such as average daily gain or age at mature weight) can therefore be predicted by the function. One of the most widely used mathematical functions to describe animal growth is the Gompertz function given below:

$$BW(t) = W_0 \exp\left\{\frac{\mu\left(1 - \exp\left\{-Dt\right\}\right)}{D}\right\}$$

As a function of time, animal BW is dependent on W_0, the initial weight of an animal (e.g., at birth or at the start of a feeding trial); the specific growth rate, μ; and decay of the growth rate, D (Macciotta et al., 2004). Calculus techniques can then be applied to this function to determine values that are of interest to producers, such as mature weight, maximum average daily gain, and the point in time in which growth is expected to be the greatest.

The appropriateness of fitting any growth function may be dependent on both the species and age of the animal. For example, if the goal is to describe the BW of goats from birth until two years of age, then perhaps a sigmoidal function would best capture the different rates of growth over time (Rocha et al., 2015). However, if BW is analyzed during a time period post-weaning but prior to maturity, a linear model of growth may be sufficient.

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Until fairly recently, analyzing nonlinear data was limited to fixed effect models. Fixed effect, nonlinear models cannot account for the between-animal variability in longitudinal growth studies (Craig and Schinckel, 2001; Bahreini Behzadi et al., 2014). Software developments such as the NLMIXED procedure of SAS (SAS Institute Inc., Carey, NC) enables users to specify both fixed and random effects to enter the model nonlinearly (SAS/STAT(R) 9.2 User's Guide, Second Edition). By partitioning the within-animal and between-animal variation, nonlinear mixed models may allow a more accurate estimation of the parameters of a growth function (Craig and Schinckel, 2001).

Although the total sale value of kid goats at auction is almost exclusively based on BW, final BW and growth are not the only factors that determine net profit from the raising of market kids. The cost associated with feed intake during growth is also of great importance. Therefore, the objectives of this study were to: (1) apply linear and nonlinear mixed models to describe the growth of weaned, intact dairy buck kids and (2) perform an economic analysis to evaluate the profit potential of raising them.

2. Materials and methods

2.1. Management and recording

All animal husbandry procedures for this study were approved by the Animal Care and Use Committee of the College of Agricultural and Life Sciences, University of Wisconsin–Madison and the University of Wisconsin–Platteville.

In May 2014, 72 weaned, intact buck kids of mixed dairy breeds were purchased from 3 commercial dairy goat farms located in East-Central Wisconsin. The kids were divided between the University of Wisconsin–Platteville (UW–P; Platteville, WI, U.S.A.; location: 42.7°N, 90.5°W) ($n = 40$) and the University of Wisconsin–Madison (UW–M; Madison, WI, U.S.A.; location: 43.1°N, 89.4°W) ($n = 32$).

The goat housing facility at UW–P was an enclosed pole barn with the end door open for ventilation, similar to the barns found on many farms. At UW–M, the goats were housed in an enclosed, environmentally-controlled building on slatted metal floors. At both locations, the kids were given approximately 2 weeks to orient themselves to their new environment during which time they received vaccinations for enterotoxemia and contagious ecthyma and were treated for respiratory disease. During this time, the kids had *ad libitum* access to a pelleted starter diet containing 18.5% crude protein (Big Gain Inc., Lodi, WI) as well as chopped grass hay.

Following the orientation period, the goats were weighed, separated into smaller pens and switched to a pelleted grower diet containing 16% crude protein (Big Gain Inc., Lodi, WI) for the duration of the growth trial. The start and end weights of all kids were calculated as the average of weights recorded on two consecutive days. At UW–P, the 40 kids were randomly allotted to 4 pens. Due to a large variation in starting weights at UW–M, the 32 kids were separated into 2 heavy pens and 2 light pens. Table 1 summarizes the characteristics of the kids in pens at both locations. The average starting weights were similar across pens at UW–P and between the two heavy pens (pens 1 and 2) and between the two light pens (pens 3 and 4) at UW–M.

During the feeding trial at UW–P, kids were full-fed the grower diet at the amount that they would voluntarily consume each day while kids at UW–M had *ad libitum* access. Kids were limit-fed a very small amount of dry chopped hay at both locations. On kid weigh days at UW–M, the pen feeders and any remaining feed were weighed so that the total pen feed disappearance could be calculated between weigh days and for the entire trial period. At UW–P, weight of feed placed in feeders was recorded, and total weight of feed fed to each pen was determined during the entire trial period. The UW–P feeding trial lasted 51 days for all kids. At UW–M, the kids from pens 1 and 2 were on trial for 53 days while the kids from pens 3 and 4 spent 95 days on trial (Table 1).

2.2. Statistical models for growth

The birth dates of the kids were not known so BW had to be expressed relative to days on feed rather than days of age. Since kids were intentionally sorted by weight to the two locations, as well as to pens at UW–M, three groups were created: all four pens at UW–P, the two heavy pens at UW–M, and the two light pens at UW–M. Two indicator variables signified which group a kid belonged to: $group_L$ (1 if the kid was from the UW–M light pens, 0 if not) and $group_H$ (1 if the kid was from the UW–M heavy pens, 0 if not) (Gossett et al., 2007).

To analyze BW over time, both linear and nonlinear mixed models were applied using the NLMIXED procedure of SAS (Version 9.3). The growth model that was linear with respect to time was as follows:

$$y_{ij} = b_{0i} + (b_{1i} \times \mathrm{day}_{ij}) + e_{ij}$$

$$b_{0i} = b_{0P} + d_{0L}group_{Li} + d_{0H}group_{Hi} + \mathrm{kid}_{0i}$$

$$b_{1i} = b_{1P} + d_{1L}group_{Li} + d_{1H}group_{Hi}$$

where y_{ij} is the j^{th} BW record of the i^{th} kid, day_{ij} is the corresponding number of days on feed, b_{0i} is the intercept, b_{1i} is the slope, and e_{ij} is the residual error. The random component of the intercept, kid_{0i}, was assumed to be normally distributed with a mean of zero and variance $\sigma^2{}_{k0}$. The UW–P kids have a value of zero for their $group_L$ and $group_H$ indicators, so the estimates of the intercept and the slope for a given group are expressed relative to the UW–P kids (b_{0P} and b_{1P}, respectively). Therefore, the group effects of the intercept and slope (d_{0L} and d_{0H}; d_{1L} and d_{1H}, respectively) estimate the deviation of the UW–M light and UW–M heavy kids from the UW–P kids for the specified parameter.

The Gompertz function that allowed nonlinear analysis of growth with respect to time was modeled as follows:

$$y_{ij} = W_{0i}\exp\left\{\frac{\mu_i\left(1 - \exp\left\{-D_i \times \mathrm{day}_{ij}\right\}\right)}{D_i}\right\} + e_{ij}$$

$$W_{0i} = W_{0P} + d_{WL}group_{Li} + d_{WH}group_{Hi} + \mathrm{kid}_i$$

$$\mu_i = \mu_P + d_{\mu L}group_{Li} + d_{\mu H}group_{Hi}$$

$$D_i = D_P + d_{DL}group_{Li} + d_{DH}group_{Hi}$$

where y_{ij} are the observed BW records, the Gompertz parameters (W_0, μ, and D) were as described earlier, and e_{ij} is the residual term. The random component of the initial weight parameter, kid_i, was assumed to be normally distributed with a mean of zero and variance $\sigma^2{}_{kW}$. As with the linear model, the estimates of the parameters of the nonlinear model are expressed relative to the UW–P kids (W_{0P}, μ_P, and D_P). The group effects (d_{WL} and d_{WH}; $d_{\mu L}$ and $d_{\mu H}$; d_{DL} and d_{DH}) estimate the deviation of the UW–M light and UW–M heavy kids from the UW–P kids for the specified parameter.

The linear and nonlinear models were compared subjectively with the supplied SAS fit statistics: −2 log likelihood (−2LL), Akaike information criterion (AIC), and Bayesian information criterion (BIC). These statistics can be used when comparing different models for the same data (SAS/STAT(R) 12.1 User's Guide). The AIC and BIC statistics offer two different ways of adjusting the −2LL for the number of parameters present in the model, with BIC penalizing