A DESCRIPTION OF THE DYNAMICS OF FETAL GROWTH IN SHEEP

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SUMMARY

Two mathematical models which describe the dynamics of fetal growth in ewes were proposed for study. The models are basically of exponential form and take into consideration of the effects of stage of gestation (T), level of nutrition (L), and number of fetuses (N) on the total fetal weight (W).

Model I: \( W = b_0 \times e^{(b_1 + b_2 N + b_3 L + b_4 T) T} \)

Model II: \( W = b_0 \times e^{b_1 N + (b_2 + b_3 L + b_4 T) T} \)

By using a stepwise regression technique, these models were tested against experimental data. It was found that the level of nutrition used in this study did not have a significant effect on the growth rate, however, all other factors are highly significant (\( P<.01 \)) for both models. Model II closely predicted the total fetal weight for both singles and twins throughout the gestation period while Model I over-predicted the total fetal weight for twins at later stages of gestation. As a result, the following equation is proposed to describe the fetal growth of Targhee ewes at higher than maintenance conditions:

\( W = 0.000103 \times e^{0.614N + (0.1281 - 0.00038T) T} \)

An equation of this form should be useful in interpreting prenatal growth data for other breeds and species. Other factors which may influence the dynamics of fetal growth like maternal age or weight could be incorporated into an equation of this type. (Key Words: Fetal Growth, Sheep, Production Equation, Targhee.)

INTRODUCTION

Much has been written on the mathematical expression of the prenatal time-weight relationship in several species. Most frequently these equations are in the exponential form, as found by Mitchell et al. (1931), Brody (1945), Weinback (1941) and Laird (1966). Some authors (Langlands and Sutherland, 1968; Rattray et al., 1974) used a third or fourth degree polynomial to express this time-weight relationship. However, in addition to the prenatal time, other factors have been reported as having effects on fetal weight. Rattray et al. found significant differences in fetal weight among singles, twins and triplets. The influence of maternal nutrition on prenatal development in sheep has been reviewed by Everitt (1967). The aim of this investigation was to develop a general mathematical model which could incorporate important variables which influence prenatal growth. A successful model should have biological meaning and aid in the interpretation of prenatal growth data.

MATERIALS AND METHODS

Theory. The basic exponential form of growth was adopted for the development of a model for fetal growth. This exponential form is based on the principle that fetal growth can be treated as a first order process, i.e.,

\[ \frac{dW}{dT} = kW \]  (1)

where \( W \) is fetal weight, \( T \) is time in days from mating and \( k \) is instantaneous growth rate. Equation (1) simply states that the rate of growth at time \( T \) is proportional to the fetal weight. By integrating (1), the usual exponential form for growth

\[ W = W_0 e^{kT} \]  (2)

where \( W_0 \) is the initial weight of fetus, is obtained.

Based on this exponential form of growth, two models were proposed which incorporate the effect of level of nutrition (L), stage of gestation (T), and number of fetuses (N) on total fetal weight (W) at different times of gestation.
Model I: \[ W = b_0 e^{(b_1 + b_2 N + b_3 L + b_4 T) T} \]  
Model II: \[ W = b_0 e^{b_1 N + (b_2 + b_3 L + b_4 T) T} \]

In the context of this study, level of nutrition (L) is defined as ME intake/(BW^{3/4} \times 100). This is not an absolute level, rather it is an index number. The stage of gestation (T) is defined as the time in days from conception minus five. This definition was chosen since it has been shown in mouse that embryo does not increase in weight during the period from fertilization to blastocyst expansion (Brinster, 1967) and it takes at least 5 days for blastocyst information in the sheep. Thus, total fetal weight is treated as constant from conception to day five of gestation.

In Model I, the initial fetal weight is assumed to be constant \((W_0 = W_s = b_0)\) and instead of having a constant instantaneous growth rate, \(k\), as in equation (2), it is proposed that \(k\) is a variable parameter which is a function of level of nutrition, number of fetuses, and time of gestation, i.e.

\[ k = b_1 + b_2 N + b_3 L + b_4 T \]

Model II is slightly different from Model I, in that, it is proposed that the number of fetuses does not affect instantaneous growth rate, rather, it affects the total initial fetal weight, i.e.

\[ W_0 = b_0 e^{b_1 N} \]

\[ k = b_2 + b_3 L + b_4 T \]

Equations (3) and (4) are the proposed models for fetal growth and will be the basis for our analysis.

**Experimental Data.** The data used in testing the proposed models and in deriving the values for parameters are from the animals used in the comparative slaughter experiment reported by Rattray et al. (1973). A total of 103 ewes were killed at approximately days 70, 100, 125 and 140 of gestation. They were individually fed from about day 45 of pregnancy and were fed at approximately maintenance until day 70 of gestation, after which they were offered approximately 1.5 or 2.0 times maintenance. At slaughter the gravid uterus of the pregnant sheep was dissected and the total fetal weight and number of fetuses were recorded. Since only nine ewes had triplets, data from these ewes were not used. As a result, the models were analyzed only for singles and twins with a total of 94 observations.

**Statistical Method.** In order to fit the proposed models with experimental data, logarithmic transformations were performed on equations (3) and (4) which resulted in the following:

Model I: \[ \log_e W = b_0' + b_1 T + b_2 (N \times T) + b_3 (L \times T) + b_4 T^2 \]

Model II: \[ \log_e W = b_0' + b_1 N + b_2 T + b_3 (L \times T) + b_4 T^2 \]

where \(b_0' = \log_e b_0\). A stepwise regression technique (Dixon, 1970) was used to test the significance of each term and to obtain the values for each coefficient.

**RESULTS AND DISCUSSION**

The results of the stepwise regression on logarithmic transformed equations showed that the term L \(\times\) T is not significant where all other terms are highly significant \((P<.01)\) for both models. The nonsignificance of the term L \(\times\) T means that the rate parameter \(k\) was not affected by the level of nutrition used in this study. Salmon-Legagneur (1967) concluded from their experiment that the only nutritional effect on fetal weight is generally as a result of underfeeding. Since the level of nutrition ranged from approximately 1.5 to 2.0 times maintenance in the data used here, our finding tends to agree with that of Salmon-Legagneur. The values for coefficients of other terms for both models are presented in Table 1. The biological means of those coefficients will be discussed separately for each model.

| TABLE 1. VALUES (+- SE) FOR REGRESSION COEFFICIENTS FOR MODEL I AND II |
|-----------------|-----------------|-----------------|-----------------|
|                 | \(b_0\)         | \(b_1\)         | \(b_2\)         | \(b_4\)         |
| Model I         | -8.268          | .1204 (+ .0046) | .0053 (+ .0002) | -.00038 (+ .00002) |
| Model II        | -9.185          | .6130 (+ .0166) | .1281 (+ .0033) | -.00038 (+ .00002) |
In Model I, since \( b'_0 = \log_e b_0 = \log_e W_0 \), \( b'_0 = -8.268 \) will give a value for \( W_0 \) equal to 0.00026 kilograms. Even though this value is much higher than the true value for fetal weight at day five, the fact that it is a very small positive number should make it biologically acceptable. This high initial value is probably due to the lack of data points in the early stage of gestation. The terms \( b_1 + b_2N \) could be thought of as the basic instantaneous growth rate for singles (when \( N = 1 \)) and twins (when \( N = 2 \)). The negative value of \( b_4 \) means that the basic instantaneous growth rate is decreased by 0.00038 each day as gestation progresses. This is in agreement with Laird (1966) who used an exponential decay factor to express this decreased growth rate with increasing age.

In Model II the relationships are: \( W_0 = b_0 e^{b_1N} \) and \( b'_0 = \log_e b_0 \). With values for \( b'_0 \) and \( b_1 \) in table 1 the calculated initial fetal weight \( W_0 \) is 0.00019 kg for singles and 0.00035 kg for twins. The value of \( b_2 \) can be treated as the basic instantaneous growth rate which decreases at 0.00038 (\( b_4 \)) per day as gestation progresses.

The graphical representations of Model I and Model II, with the effect of level of nutrition ignored, are shown in figure 1 and figure 2, respectively. The experimental data are taken from Rattray et al. (1973). It can be seen from these figures that Model I clearly over-predicts the total fetal weight for twins at later stages of gestation. At the same time Model II seems to predict very well the total fetal weight for both singles and twins with no apparent error pattern.

As a result of this analysis, the following equation (Model II) describes fetal growth in Targhee ewes under normal feeding:

\[
W = .000103 e^{.613N} + (.128 - .00038T) T
\]

With the exception at a very early stage of gestation, this equation could be used to predict the total fetal weight for singles and twins at different stages of gestation. More important, an equation of this form could be useful in interpreting prenatal growth data for other breeds and species. Also, other factors such as age and body weight of the dam can be incorporated into the equation to study their effects on the dynamics of prenatal growth.
Figure 2. Total fetal weight as a function of stage of gestation and number of fetuses — Model II. (Data points are taken from Rattray et al. 1974)

LITERATURE CITED

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