



Revue semestrielle – Université Ferhat Abbas Sétif 1

REVUE AGRICULTURE



Study of growth for longitudinal balanced data of Ouled-Djellal Algerian breed Sheep

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ARTICLE INFO

L'histoire de l'article

Reçu : 09/10/2018

Accepté : 31/12/2018

Keywords:

Algeria, Sheep, Ouled-Djellal, Linear Multilevel growth Model, Mixed Models, Growth curve, longitudinal data.

Mots clés :

Algérie, Ovins, Race Ouled-Djellal, Modèle multiple linéaire de la croissance, Modèles mixtes, courbe de croissance, données longitudinales.

ABSTRACT

Repeated monthly, body weight measurements from birth to 6 months of age of 138 sheep lambs were used for analysis. Linear mixed-effects model was developed by fitting unconditional linear growth, unconditional quadratic growth and conditional quadratic model, giving different error variance-covariance structures. Covariate such as progeny birth type (pbt) was used as well for the analysis. Gender or sex was not significant and was omitted from the analysis. The best model was identified using 4 information criterions. Conditional quadratic model with covariance structure fitted using mixed model approach was found to be good. In this study, modelling technique was assessed in the intention of predicting balanced longitudinal growth data for the first time concerning the Ouled-Djellal breed sheep. More analyses are suggested for the Algerian several sheep breed in order to assist animal breeders to models longitudinal animal growth rate.

RESUME

Etude de la Croissance pour des Données Longitudinales pour la Race de Mouton Ouled-Djellal (Algérie)

La présente étude a trait à la croissance de 138 agneaux de race Ouled-Djellal, de la naissance à l'âge de 6 mois. Elle a été réalisée dans la région Est de l'Algérie. Plusieurs modèles linéaires mixtes ont été testés: le non conditionnel linéaire, le non-linéaire quadratique et le conditionnel quadratique modèle de croissance. Dans la présente investigation, la technique de modélisation a été mise à profit avec l'intention de pouvoir prédire la croissance des agneaux de race ouled-Djellal. Selon les résultats obtenus, d'autres analyses sont à suggérées afin d'aider effectivement les éleveurs dans leur entreprise.

Introduction

In Algeria, sheep breeds represent a very important national resource. They are primarily reared for meat. One of these breeds, the Ouled-Djellal is the most numerous and the most important for several reasons, which are successively: well adapted to its environment, ability to tolerate harsh climates, good recovery capacity from draught, suitability to low input systems because of its ability to thrive on poor diet, to mate in all seasons and to tolerate long distance walking (Trouette, 1933; Sagne, 1950; Cabbée, 1959; Chellig, 1992; Mennani et al., 2011 and Dekhili, 2014). In spite of its importance, information on sheep resource is scarce. From this point of view, growth constitutes an important trait of economic interest to investigate for the Ouled-Djellal breed. Growth could be evaluated by growth rate, by weight and size increases at different stage of life (Arango and Van Vleck, 2002). The type of data are commonly recorded on the same animal at various ages or times

(monthly) resulting in longitudinal growth data, where they provide valuable information about individual changes (Ganesan et al., 2014). Due to many statistical problems, standard approaches, such as ANOVA, MANOVA and regression models, become not appropriate (Ganesan et al., 2014), because the common statistical assumptions are not met for longitudinal growth data. Growth models are designed for exploring longitudinal data on individuals over time, where the main idea is to characterize the way of outcome changes over time (ages) and to identify the predictors of that change. Random coefficient model (Laird and Ware, 1982) using linear mixed model approach, which allows the growth parameters of each animal to be considered as random effects in the model, constitutes an interesting way to describe longitudinal data. Linear-multilevel growth models have been applied by many authors (Puyalto et al., 1997; Green et al., 1998) to explore such longitudinal growth data. As there is no work done in Algeria to analyse longitudinal animal growth data, the main objective of this investigation is to analyse longitudinal sheep growth data using Linear Multilevel Model (LMM) for predicting longitudinal growth data of the Ouled-Djellal Algerian sheep.

Materials and Methods

Data

The data used in this study were obtained from 138 Ouled-Djellallambs (70 as single born; 68 as twin born) giving a total of 966 body records. The field records were obtained from Ben Aichouche State Farm located in the East of Algeria during year 2010 (Mennani et al., 2011). Sheep were managed in the extensive way. The mating period started in March (natural flushing) and lambing was concentrated during September. The lambs were fed on natural pasture and kept with their mothers until the weaning age (3 months). In winter, animals are kept indoors, and on pasture in late spring (March), summer and autumn. All animals were weighed at birth, 1, 2, 3, 4, 5 and 6 month of age. All records were written individually in special document and saved in an Excel spread sheet file. Number of measurement for each animal was the same (balanced). There were seven body weights recording per lamb in the present study. Variable (t) which indicates the age of measurement of body weight or time of weighing of lamb, when times= 0(at birth), 1 (1 month), 2 (2 month), 3 (3 month), 4 (4 month), 5 (5 month) and 6 (6 month), birth type of lamb (pbt) do not change across time, was used as covariate (coded 1 for single and 2 for twin) in the analysis.

Methods of analysis

The linear-individual growth model which is an extension of the mixed-effects models described by Rao (1965) for growth curve and by Laird and Ware (1982) for longitudinal data analysis was used in this investigation. The model used was specified according to the notation of Singer (1998) as follows:

$$Y_{ij} = \pi_{0j} + \pi_{0j}(\text{Time})_{ij} + r_{ij},$$

$$\text{where: } r_{ij} \sim N(0, \sigma^2) \text{ and } \pi_{0j} = \beta_{00} + u_{0j},$$

$$\text{where } \begin{pmatrix} u_{0j} \\ u_{1j} \end{pmatrix} \sim N \left[\begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{pmatrix} \tau_{00} & \tau_{01} \\ \tau_{10} & \tau_{11} \end{pmatrix} \right]$$

$$\pi_{1j} = \beta_{10} + u_{1j}$$

This can be written as:

Model-1(Unconditional individual growth model):

$$Y_{ij} = [\beta_{00} + \beta_{10}\text{Time}_{ij}] + [u_{0j} + u_{1j}\text{Time}_{ij} + r_{ij}];$$

Model-2 (Unconditional quadratique):

$$Y_{ij} = [\beta_{00} + \beta_{10}\text{Time}_{ij} + \beta_{20}\text{Time}_{ij}^2] + [u_{0j} + u_{1j}\text{Time}_{ij} + u_{2j}\text{Time}_{ij}^2 + r_{ij}];$$

Model-3 (conditional quadratique):

$$Y_{ij} = [\beta_{00} + \beta_{10}\text{Time}_{ij} + \beta_{20}\text{Time}_{ij}^2 + \beta_{01}\text{pbt}] + [u_{0j} + u_{1j}\text{Time}_{ij} + u_{2j}\text{Time}_{ij}^2 + u_{2j}\text{pbt}_{ij} + r_{ij}];$$

Where:

Y_{ij} : denotes the i^{th} animal body weight at month or Time j

Fixed parts are:

β_{00} : is the estimate of the average intercepts across individuals or mean birth weight at time 0;

β_{10} : is the estimate of the average slope across individuals or the mean growth rate;

β_{20} : is the estimate of the quadratic average slope across individuals;

β_{01} : is the estimate of the average covariate slope across individuals.

Random parts are:

- u_{0j} : is the individual animal deviation from the birth weight;
- u_{1j} : is the deviation from the mean growth rate;
- u_{2j} : is the quadratic deviation from the mean growth rate;
- $u_{2j}pbt_{ij}$ is the deviation from the mean across the covariate;
- r_{ij} : within individuals residual.

Models using the restricted maximum-likelihood (REML) method with identical random effects but with different fixed effects were used using PROC MIXED procedure of SAS (1996). Models were compared according to -2 Res Log Likelihood, AIC (Akaike information criterion), AICC (corrected Akaike Information Criterion) and BIC (Sawa's Bayesian Information Criterion) criterion's information. Using these informations, the model with the smallest values was retained.

Results and Discussion

Description of data

The individual animal growth pattern illustrated up to 6 months of age using profile plot is shown in Figure 2, which clearly shows that the growth shape of different animals displays different lines. The lambs differ in their initial birth weight and in their growth rate. Variances for different time of measurement (age) are also observed to be non-constant and were found to increase as the age increases (Figure 1).

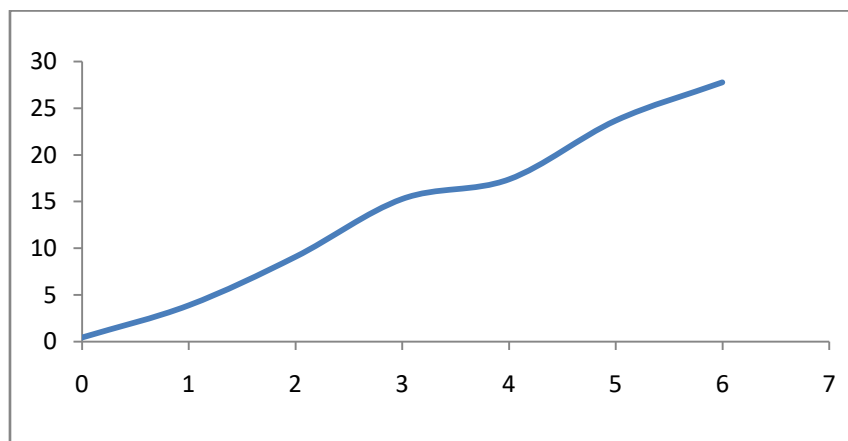


Figure 1: Increase of variances with time of measurement

Models Fitting

Model-1:

From the results of model-1 (Table1), which is an individual growth model with no level-2 covariates, the estimate of the fixed effects are: $\beta_{00} = 4.71\text{kg}$ is the intercept (average birth weight) across individuals (average value of Y when time=0 or at birth) which is a realistic weight but under extensive way of breeding, and the $\beta_{10} = 3.5\text{kg}$ is the estimate of the average slope across lambs or average change. Both estimates were found to be highly significant ($P < 0.0001$). The standard errors of these fixed parameters were small (0.2 and 0.09) giving large t-statistics (4.75 and 7.5) and low p-values ($P < 0.0001$), deducing that on the average there is statistically significant relationship between time of measurement (age) and weight. According to the random effects, the estimates of variance of intercept, slope and covariance were of 1.94, 0.98 and 1.02 units, were found to be statistically highly significant (Wald Z test), indicating that the initial status (birth weight) and linear growth rates were not constant (Figure 2). The estimated value of the residual (σ^2) is 2.99 ($P < 0.0001$) with standard error of 0.16. Standard errors of these estimates and hypothesis test of the null hypothesis indicate that these sample variances and covariance are 0. These show that lambs differ in their average birth weight and there is more variation among individuals within lambs. The covariance parameter estimated for this model (Model-1), indicate the variation of the intercepts and slopes across individuals. The results of 1.94 (τ_{00}), tell us about the variability in the intercepts, 0.98 (τ_{11}) tell us about the variability in slopes and 1.02 is the covariance ($\tau_{01,10}$) between intercepts and slopes. There is a clear evidence of the existence of variability in both the intercepts and slopes, where individuals do differ greatly in the average weight. The correlation between intercepts and slopes is very high (0.74) and highly significant ($P < 0.0001$), showing a strong indication that the effects of time on weight differ depending upon the average weight in the individual. The values of the

information criterion for this model are presented in Table2 and the number of parameters needed to be estimated was 3.

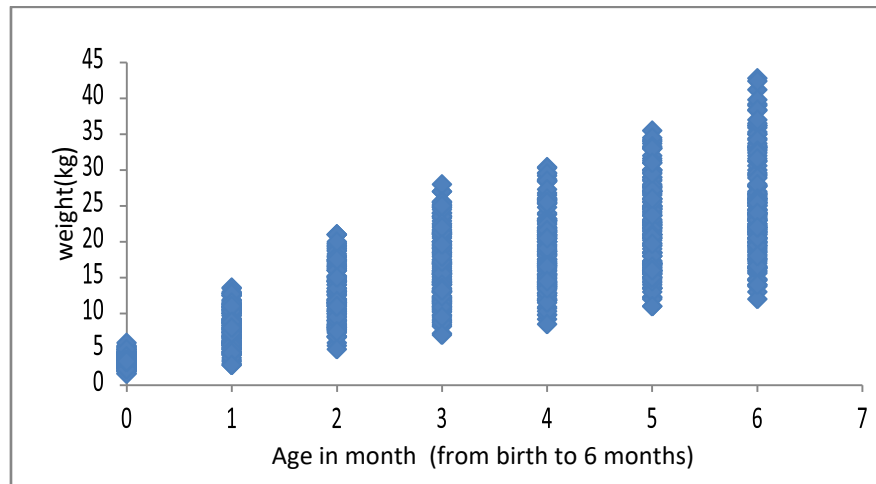


Figure 2 : Graphing change using weight plot for all lambs

Model-2:

Results of the unconditional quadratic Model-2 are presented in Table1. The variance of intercept, slope and quadratic slope were found to be highly significant ($P < 0.0001$), inferring that the variability in these parameters might be explained by between animal predictors. The standard errors of these fixed parameters were small giving large t-statistics (5.9 and 7.7) and low p-values, inferring that on the average there is statistically significant relationship between time of measurement (age) and weight. The estimate for the intercept (3.5) indicates that the estimated average lamb mean, controlling for age is 3.5kg. The estimate for the slope (4.9) implies that the estimated average slope representing the relationship between age and weight is 4.9kg. The quadratic slopes or t^2 (-0.24) is negative suggesting that growth rate is lowering and the curve is decelerating or tapering off as age increases. At later ages (time), lambs start to graze poor and dry grass which coincides with January-February, where temperature is low and there is no good and rich grass, which influences negatively on the growth rate. In Model-2, the residual variance is 2.04, which is much lower than the error of Model-1 (2.99). Inclusion of age squared in the Model-2, has explained 31.7% of the explainable variation within lambs. Estimates of random variances (τ_{00}) were 2.4, which tells about the variability in intercepts, 1.02(τ_{11}) which tells about the variability in slopes, and 0.5, tells about the variability in quadratic slopes. All estimates have low standard errors and they are highly significant ($P < 0.0001$). Intercepts are very variable where lambs do differ in average weight even after controlling for the effects of age. The slopes are also variable. The estimates of the information criterions (Table-2) for this model-2 have reduced and the number of parameters estimated was 3. The results of τ_{00} and τ_{11} for Model-1 and Model-2 (Table-1) show the existence of variation in both components, the intercepts and slopes, that could be better explained by a level 2 covariate (Singer, 1998).

Table 1. Model parameter estimates (SE) for the various mixed model/s.

Fixed Effects	Model-1	Model-2	Model-3
Intercept	4.71(0.2)***	3.5(0.15)***	4.8(0.4)***
Age	3.50(0.09)***	4.9(0.11)***	4.9(0.1)***
Age ²		-0.24(0.01)***	-0.23(0.012)***
Birth type		-	-0.71(0.07)***
Random variance			
Intercept	1.94(0.4)***	2.4(0.4)***	1.03(0.2)***
Slope	0.98(0.13)***	1.02(0.6)***	1.02(0.1)***
Quadratiquess lope		0.05(0.5)***	0.05(0.01)***
Residual	2.99(0.16)***	2.04(0.13)***	2.03(0.09)***

***: $P < 0.0001$; (): Standard Error(SE)

Model-3:

The results of linear quadratic with predictor progeny birth type (pbt) or level 2 with pbt as covariate are given in Table 1 (Model-3). The estimate of intercept, slope and quadratic slope are found to be highly significant ($P < 0.0001$) and so were their variance estimates (Table 1). The estimate for the intercept and slope (i.e. β_{00} and β_{10}) are the same of those of the unconditional model or Model-1. Intercept for Model-3 is of 4.8kg weight at birth, this could be achieved but under, only, a real intensive breeding program. The latter is highly significant ($P < 0.0001$) with low standard error (0.4) and is higher to the S.E. of model-1 (0.2). The estimates of the slope (β_{10}) are different (4.9) to the basic Model-1 (3.50). This estimate (β_{10}) is also highly significant ($P < 0.0001$) with a low standard error (0.1). This allows to reject the null hypothesis that either of these 2 parameters are 0 in the flock investigated. Basically, the average lamb began with a score of 4.8 and gained 4.9 points per testing occasion. Statistically, there is a significant and positive relationship between age and weight. The coefficient for the covariate (pbt) in Table 1 is of 1.02, positive and highly significant ($P < 0.0001$) and with low S.E. (0.1). The latter (pbt) captures the relationship between the covariate and initial status. With respect to the growth rates, there is an effect of the covariate as well. When comparing the estimates for the variance-covariance matrix from those of Model 1 (basic), and when it comes to estimating initial status, inclusion of the covariate did helped in reducing the size of the variance component for intercepts from 2.99 (Model 1) to 2.03 for Model 3 or about 23.0% of reduction. This means that the level-2 variable Age (Time) explains a large proportion of the variation of lamb to lamb variation in mean weight achievement. As, the variance component for growth rates went from 0.98 (Model 1) to 1.02 in Model 3, or increase of 40.8%, therefore the inclusion of the covariate improved the fit of growth rates. The covariance estimate for this model is 0.53 with standard error 0.1, which yields a p-value of 0.0001. This is saying that there is evidence that the effect of growth rates depending upon the weight average. Results presented in Table1, are assuming that there is a real relationship between initial status, growth rates and the covariate, suggesting that the growth curve is concave to the time axis or the instantaneous linear growth rates is decreasing with the status of birth. Adding to this, the estimates of the information criterions (Table2) for Model-3 have reduced and the number of parameters estimated was 3. The estimate of the residual (σ^2) remained unchanged at 2.03 as in Model-2. From table 1 and Model-3, we can construct prediction equations for the different combinations. Thus, the predictive equation for single born lamb is:

$$y_{ij}(\text{Singles}) = (3.5 + (4.9)t - (0.24)t^2)$$

And for twins:

$$y_{ij}(\text{Twins}) = \underbrace{[(4.8 + 4.9t - 0.23t^2 - (0.71\text{pbt})]}_{\text{Fixed effects}} + \underbrace{[(1.03 + 1.02)t + (0.05)t^2]}_{\text{Random effects}}$$

Table 2. Summary of the performance of the various linear mixed models.

Model	-2RLL	AIC	BIC	AICC	Khi-2/df	N° of Parameters
1. Model-1	4385.6	4393.6	4405.4	4393.7	1420.1***/3	3
2. Model-2	44127.8	4135.08	4147.5	4135.9	1654.3***/3	3
3. Model-3	4072.8	4080.8	4092.5	4080.9	1467.8***/3	3

Conclusion

In this study appropriate statistically linear mixed modelling was used for the purpose of predicting balanced longitudinal growth data of Ouled-Djellal sheep of Algeria. Three types of statistically appropriate linear mixed models were used for the purpose of predicting balanced longitudinal growth data of Ouled-Djellal sheep. Conditional quadratic model progeny birth weight (as covariate) using mixed model approach was b showing marked influence on the growth parameters. Quadratic slopes or change at later ages was significant in both cases in reducing weight at later time of measurements. This is mainly due to the way of breeding and to the adaptation of sheep to the Algerian environment. This model can be exploited by animal breeders or technicians to bring about overall improvement in productivity. At last, it is strongly suggested that more analyses are needed to verify these results or to improve them.

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