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Restoration and rehabilitation of temperate pastures using grazing management – A biometrical approach

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RESUME – *"Restauration et réhabilitation de pâturages tempérés à travers la gestion pastorale – Une approche biométrique". Pour les expériences à long terme, nous examinerons les effets des stratégies de gestion sur les espèces pastorales au fil du temps ; il existe d'importants points obscurs concernant les zones pour la conception des essais et l'analyse des données résultantes. Une énumération de la diversité originelle est essentielle pour éviter un éventuel biais lors de l'estimation des effets des traitements dû au manque d'uniformité. Les séries de données résultantes, répétées, présentent un problème de modélisation significatif avec des temps inégaux entre mesures, des variances hétérogènes sur ces périodes et des corrélations décroissantes entre parcelles lorsque augmente le temps entre les mesures. Cet article décrit l'ajustement aux données longitudinales par des splines cubiques de lissage en employant la méthode de Verbyla et al (1999), qui utilise les modèles linéaires mixtes et le maximum de vraisemblance résiduelle (REML) et inclut la modélisation de la covariance appropriée à la structure des données.*

Mots-clés : *Pâturage, conception des essais, analyse des données, temps, splines.*

Introduction

Livestock production in the higher rainfall areas of southern Australia (>600 mm a.a.r.) usually occurs on perennial pastures based on phalaris (*Phalaris aquatica* cv. Sirosa) or cocksfoot (*Dactylis glomerata*). Variability in livestock prices often results in sporadic inputs of fertiliser, such that the perennial components may be replaced by annual species. This results in lower pasture production, poorer feed quality and reduced ground cover. However, resowing pastures may not be economic, given poor persistence under sub-optimal nutrition. A lower cost option may be the use of strategic grazing-resting periods to improve the growth and vigour of the perennials. This paper reports on such an approach, emphasising the biometrical aspects of trial design and analysis of data.

Materials and methods

Design and treatments

From September 1997 to February 2001 a grazing management study was conducted at Nundle (a.a.r. 834 mm, Clewett *et al.*, 1999) on the North West Slopes of NSW (31º24'S; 151º07'E 590 m a.s.l.). The pasture was sown in 1992 and consisted of phalaris (*Phalaris aquatica* cv. Sirosa), subterranean clover (*Trifolium subterraneum* var Seaton Park) and lucerne (*Medicago sativa* L. cv. Aurora). In early spring 1997, 3 replicates of 4 grazing treatments were allocated to 12 plots (each 0.49 ha) in a randomised block design. The 4 grazing treatments were: Treatment 1- continuous grazing (12.3 sheep/ha) (control); Treatment 2 - continuous grazing (6.1 sheep/ha); Treatment 3 - continuous grazing at 12.3 sheep/ha except for a 4-6 week period in spring and autumn when stocking rate was reduced to 6.1 sheep/ha and Treatment 4 - continuous grazing at 12.3 sheep/ha except for a 4-6 week period in spring when stock were excluded.

Design features

The characterization of experimental units (plots) prior to the commencement of the trial was considered in the allocation of treatments to plots. Cox (1982) proposed that where covariates are available before the experiment commences, the treatment allocation might be adjusted to take account of this covariate information. An initial BOTANAL survey (dry weight rank, herbage mass and percentage green) (Tothill *et al.*, 1992) was conducted at the plot level and this information was used in the allocation of treatments to plots. Merino wethers used to stock the plots were allocated to treatments according to their weight so that initial differences in liveweights were not significant.

Statistical analysis

We focus here on the data arising from repeated measurement of the herbage mass (kg DM/ha) of phalaris. With such large fluctuation in scale for these type of data it is sensible to seek a transformation for which the assumption of homogeneity of variance may be reasonable. We therefore look at the parametric family of transformations analysed by Box and Cox (1964). Using the plotting techniques of McCullagh and Nelder (1983), it was determined that the square root transformation was the most appropriate transformation for these data. Figure 1 presents the data on the square root scale. Short-term fluctuations are apparent both at the overall mean level (e.g. day 542) and within treatments (e.g. treatment 1, day 906). It is also notable that there may be 2 phases of pasture development evident in these data, with the first 402 days representing pasture degradation during drought conditions followed by pasture recovery in the next phase. Although these 2 phases are of interest, the aim of the project was to model the persistence of phalaris, that is, we wish to determine the long-term smooth trend in the data. Verbyla *et al.* (1999) present a method for the analysis of longitudinal data using cubic smoothing splines which permits the inclusion of random coefficients, covariance modelling and estimation of non-smooth deviations at the various levels of the design. The linear mixed model is the basis of all analysis and estimation via REML (residual maximum likelihood).

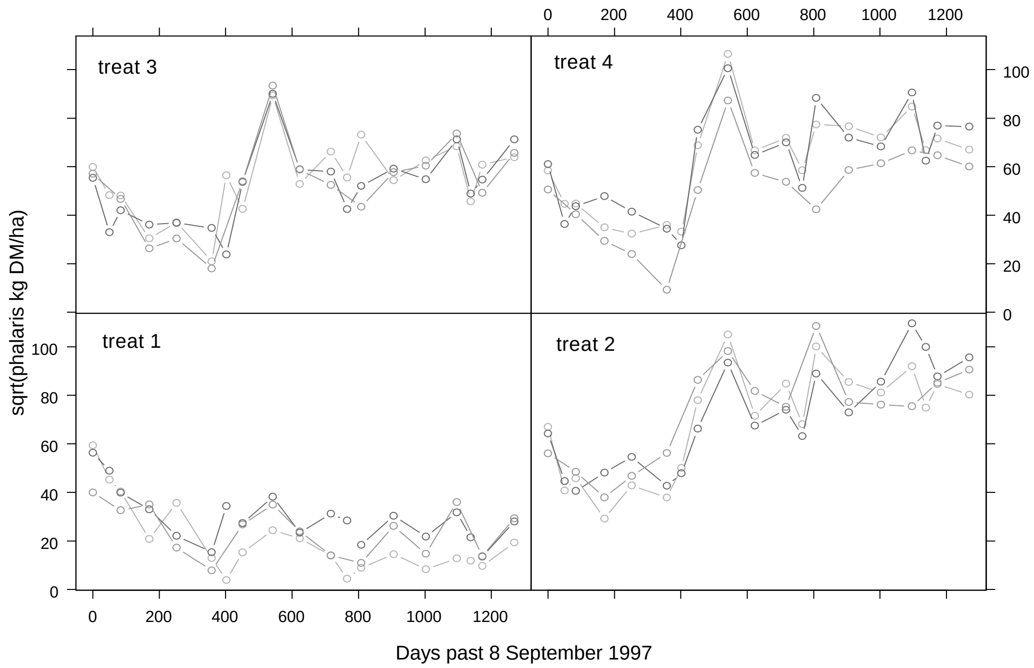

Fig. 1. Data from 3 replicates of the 4 grazing treatments on the square root scale.

Two models fitted using ASREML (Gilmour *et al.*, 1998) are examined for appropriate modelling of the data structure (Table 1).

(i) Cubic smoothing splines using all measurement times as knotpoints (points between which a cubic is fitted and at which the curve is continuous and differentiable) and including a correlation between intercept and linear trend for each plot.

(ii) Cubic smoothing splines using reduced numbers of knotpoints (White *et al.*, 1999) placed at the midpoint of each season and including a correlation between intercept and linear trend for each plot.

For each model the significance of fixed effects was determined using the Wald statistic (an approximate F-test) while the significance of each random term was examined by testing twice the change in the log-likelihood as a chi-square statistic on the appropriate degrees of freedom.

Table 1. A summary of the terms and covariance structures fitted in the two models

Strata	Terms in the Decomposition	Fixed or random
Rep		Random
Plot	Treatment	Fixed
	Residual (Plot) [C]	Random
Plot×Days	Days	Fixed
	Treatment×Days	Fixed
	Deviations(Fdays)[B]	Random
	Spl(Days)[A]	Random
	Treatment×Spl(Days)[A]	Random
	Deviations (Treatment×Fdays)[B]	Random
	Plot.Days [C]	Random
	Plot×Spl(Days)[A D]	Random
	Residual	

A. Spl(days) represents the non-linear component on days. The effects estimated being the second derivatives at the internal knot points (second derivatives at end-points are zero).
B. Fdays is a factor numbered 1 to 19. Deviations at the 'Fdays' level represent deviations at the mean level while deviations at the 'Treatment×Fdays' level represent deviations at the treatment mean level.
C. Plot and Plot×Days are linked which implies that the intercept and slope are correlated for each plot.
D. Plot×Spl(Days) is included to model the covariance structure at the plot level.

Results

There was no significant change in log-likelihood between the 2 models so we present predicted values for model 2 (Figure 2 for each plot and Figure 3 at the treatment mean level). All terms described in Table 2 were retained in the model as they were significant at $p<0.05$. There was also a correlation (0.46) between intercept and underlying linear trend at the plot level. After sheep are placed on plots (day 60) and up to day 402 the magnitude of the effects for 'fdays' are 0.67, -8.62, -8.89, -17.91, -12.60 indicating that there is some local autocorrelation at the overall mean level not accounted for by the estimated smooth persistence trend, relating to the prevailing drought conditions. The underlying linear trend for treatment 1, had a slope of –0.017 indicating an overall decline in phalaris kg DM/ha while treatments 2, 3 and 4 all indicated positive trends (slopes 0.038, 0.018 and 0.027 respectively). It is also possible to test for significant differences between splines at specific times of interest.

Discussion

From figure 1 we see that the timing of measurements in the days after return of sheep to plots varies from 24 to 125 days with some consistency from year to year in autumn (85-104 days, except for 24 days) and some consistency in spring (74-125 days). Similarly, measurements after reduction/removal of sheep in autumn occurred at between 13 and 23 days and in spring at between 6 and 31 days. With measurements taken at varying times after placement or removal/reduction of sheep, and with only 3 years of measurements it is not appropriate to model trends for particular seasons, rather, we model persistence over time while being aware of localised autocorrelation patterns. This may be achieved by the use of cubic smoothing splines as detailed in Verbyla *et al.*

(1999). The choice of knotpoints, where the times of measurement are variable, should relate to the biology.

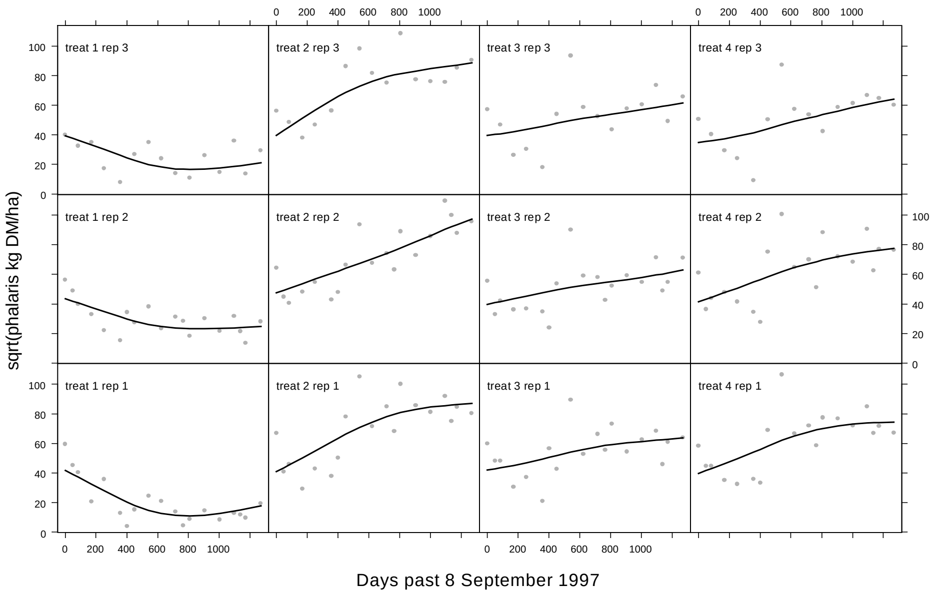

Fig. 2. Predicted plot level cubic smoothing splines.

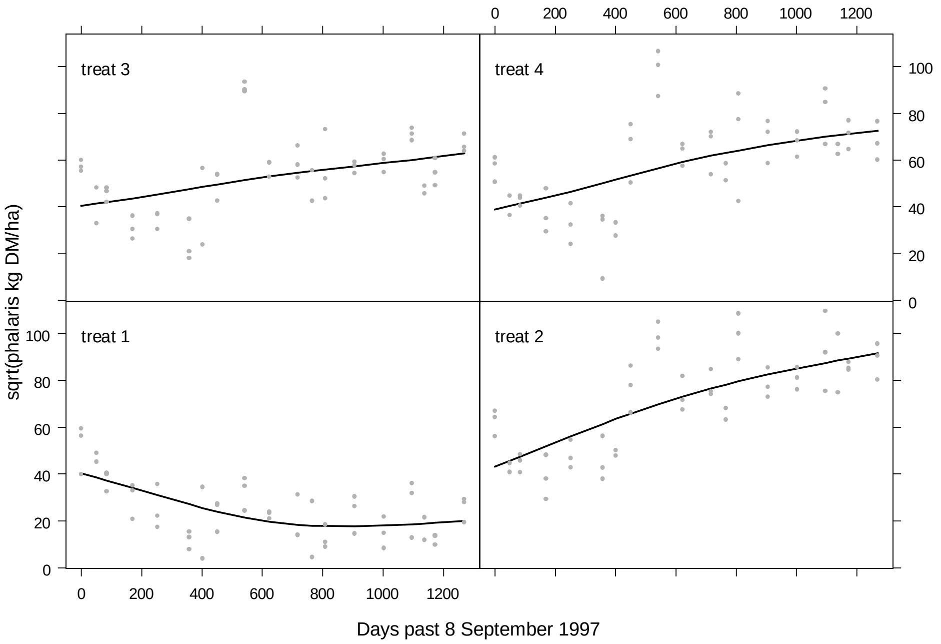

Fig. 3. Predicted treatment mean level cubic smoothing splines.

The significance of the inclusion of the ‘fdays’ and ‘treat×fdays’ terms in these spline models needs clarification. When a spline model was fitted to the data with these terms excluded, the predicted spline was an interpolant of the data. The predicted spline had greater curvature, modelling the period of degradation as well as the period of recovery. However, the aim was to model persistence and hence periods of local trend (autocorrelation) should not dominate over the modelling of long term curvilinear trend. The model which included ‘fdays’ had a higher log-likelihood and was therefore selected as the most appropriate for modelling persistence.

Cubic smoothing splines have also been used effectively to model dry matter of phalaris, cocksfoot, ryegrass and native grasses (Avery *et al.*, 2000; Garden *et al.*, 2000; Graham *et al.*, 2000; Lodge and Orchard, 2000; Virgona *et al.*, 2000). Research is continuing in the areas of appropriate covariance models such as cubic smoothing splines with decreasing plot correlations as time between cuts increases, with heterogeneous variances for each measurement time and with 'patterns' in correlations between successive measurement times.

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