ESTIMATES OF THE INCREASE IN MILK PRODUCTION DUE TO THE INTRODUCTION OF MAIZE SILAGE TO A DAIRY FARM IN KWAZULU-NATAL: A TIME SERIES APPROACH

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Abstract

A method involving time series modelling is provided for evaluating the effects of an abrupt intervention, such as the adoption of a new technology, when no control is available for comparative evaluation. The new technology was the introduction of maize silage into the feeding programme of a dairy farm in the midlands of KwaZulu-Natal. A model was developed using historical milk data from a nine-year period. The model was used to forecast subsequent milk production on the dairy farm had maize silage not been introduced, and these forecasts were compared with actual production after the introduction of maize silage. Milk production was more than 320,000 litres greater than forecast in ten seasons over a four-year period after the introduction of silage. During the same period, production was more than 14,000 litres less than forecast in one season, with the remaining six seasons estimated to be within 5% of observed values. This resulted in an estimated net gain of 305,668 litres of milk above the amount expected had silage not been introduced, representing an average increase in production of 18% per annum.

1. INTRODUCTION

The introduction of maize silage to a dairy farm feeding programme is likely to increase total farm dry matter production (Cowan & Kerr, 1984) and allow the reallocation of feed produced in summer to other periods of the year. This makes maize silage an attractive proposition for a number of dairy farmers, but most are deterred from making silage by the uncertainty of the effect it will have on farm productivity. The effects on productivity of the inclusion of maize silage in the feeding programme on a dairy farm were estimated using time series analysis techniques. The objective was to develop a model that could estimate seasonal effects and time trends in milk production before silage was introduced. Such a model could be used to forecast milk production. These forecasts could then be compared with actual production levels to estimate increases in production.

2. METHODOLOGY

A dairy farm in midlands of KwaZulu-Natal Province in South Africa, that had recently introduced maize silage into its feeding programme, was used. The farm had accurate milk production records and no major management changes, other than the introduction of maize silage, during the study period.

The 137 ha farm was located in Boston, near Pietermaritzburg. Prior to the introduction of maize silage the feeding system was based on a mix of grazed crops and pasture. In addition, approximately1.25 tonnes of concentrate were fed per cow per annum.

Maize silage was made in summer (February and March) and fed back to the cows during winter and spring (June to November). Monthly milk production was collected from 1990 to 2002 and these data were grouped together according to seasons. That is, summer production was obtained from the sum of the production for the months of December, January and February (season 4); similarly for autumn (season 1), winter (season 2), and spring (season 3). Production during autumn was taken as a base line and the effects of the other three seasons were assessed in relation to this. Maize silage was introduced into the farming system in 1998. Milk production for each season for the years from 1990 to 2002 for this farm along with the model's predictions from 1990 to 1998 and forecasts from 1998 to 2002 are shown in Figure 1.

A basic model was derived from a time series of 33 observations for the period 1990 to 1998, the period before the introduction of maize silage. Examination of the residuals from the model suggested the presence of autocorrelation between successive time intervals. To incorporate this into forecasts, an extended model was developed to include a component to represent this autocorrelation.

The technique was a modification of generalised least squares regression fitting and used multiple regression to develop a time series model (Wonnacott & Wonnacott, 1981). Dummy variables were used to describe the seasons of winter, spring and summer. The basic model is described below.

$$Y_t = \beta_0 + \beta_i t + \beta_s A + \varepsilon_t \quad (1)$$

where Y_t is the milk production (in litres) for time period t = (1,...., 33); s = 1 (autumn), 2 (winter), 3 (spring), 4 (summer); A = 1 if s = 2. 3 or 4, and 0 if s = 1; β_i are the appropriate regression coefficients; and ε_t is the random error.

The model was fitted using the statistical package GLIM (Baker & Nelder, 1987). To provide the autocorrelation adjustments to the forecasts, correlates were obtained by regressing residuals at time t on the residuals at time t = 1 (lag 1) to assess the autocorrelation in the de-trended series. The Pearson's correlation coefficient, r, obtained from the linear regression is approximately equal to the autocorrelation coefficient and can be tested for significance using the Durbin Watson test (Wonnacott & Wonnacott, 1981). The Durbin Watson test statistic was 1.14 and this was conclusive for serial correlation and below the lower bounds for the 1% significance level. The adjustment was obtained by multiplying the autocorrelation coefficient with the previous residual from the basic model. Forecasts from the basic model were then corrected by adding the appropriate autocorrelation adjustment.

Once the autocorrelation adjustment had been accounted for, the random error associated with the forecast was calculated. This involved the multiplication of the standard deviation from the residuals model by a random normal deviate generated through GLIM. The general form for the error term in the adjusted model used to allow for autocorrelation is shown below.

$$\varepsilon_t \ni \rho\, \varepsilon_{t-1} + v_t \quad (2)$$

where ρ is the autocorrelation coefficient for a lag of 1 and v_t are truly random errors having a normal distribution with a mean of zero and constant variance. Initially rainfall in each season was included in the model, but was omitted due to the low correlation (r^2 = 0.30) found between rainfall and milk production.

3. RESULTS AND DISCUSSION

The step up regression technique was used to determine the best model. Using this technique it was found that the partial regression coefficient for the season of winter was 1515 with a standard error 5151, and this coefficient was omitted from the model. The partial regression coefficients and standard errors for the model are shown in Table 1.

Table 1: Regression Coefficients and Estimates from the Basic Time Series Model from 1990 to 2002

Partial regression coefficient	Model estimates	SE
Constant β_0	69491	4011
Time trend β_1	439	97
Spring season β_3	35233	4469
Summer season β_4	27495	4483
Variance ratio = 28.19[a]		
Coefficient of determination = 74.4%		

[a] Significant ($P < 0.001$).

Forecasts estimated from the adjusted model are shown in Table 2. The confidence intervals were derived from the standard error of the forecasts obtained from the basic model and the student's *t* value for $P < 0.05$.

Table 2: Forecasts of total production in each season calculated from the adjusted model compared to actual production (litres)

Season	Observed	Model forecast	Confidence interval 95% level	Increase or decrease from forecast
Winter 97	111073	93505	8372	17568
Spring 97	140112	127571	10080	12541
Summer 98	118170	112769	10080	ns
Autumn 98	93415	89756	9310	ns
Winter 98	120877	94198	9634	26679
Spring 98	139597	128084	11178	ns
Summer 99	130611	126099	11178	ns
Autumn 99	115211	99204	10626	16007
Winter 99	152999	98573	10964	54426
Spring 99	152592	135335	12366	17257
Summer 00	120300	134896	12366	14596
Autumn 00	123600	86388	11992	37212
Winter 00	170133	88075	12338	82058
Spring 00	138793	116224	13624	22569
Summer 01	114367	119937	13624	ns
Autumn 01	95930	96409	13392	ns
Winter 01	127985	94362	13746	33623

ns = not significant at confidence interval 95% level.

The introduction of maize silage significantly ($P < 0.05$) increased milk production above the model's forecasts in 10 seasons, while there was a significant ($P < 0.05$) decrease in one season. The other six seasons showed no significant variation from forecasts. The total increase in milk yield was more than 320,000 litres above forecasts in the 10 seasons with 14,500 litres below forecasts in summer 2001. This gave a net gain over forecasted yield of over 305,000 litres of milk.

Other factors that could have had effects on total farm milk yield, such as changes in management, farming systems or rainfall, were also studied. Management did not change substantially during the study period and the only change in the farming system was the introduction of maize silage, all other inputs (i.e. pasture fertilisation and grazing) remained virtually the same. As the dairy farm was predominantly under irrigation, rainfall for each month and total annual rainfall over the study period was not considered. After the introduction of maize silage in 1998 the pattern of production changed, with autumn and winter production levels becoming much higher

(Figure 1). Actual milk production and the model's predictions before the introduction of maize silage were averaged for each season. This average production was compared with post silage production and forecasts (Figure 2).

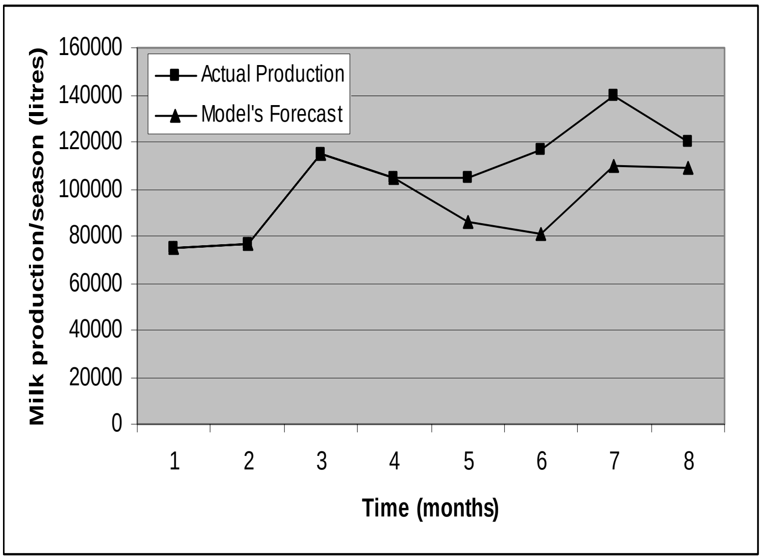
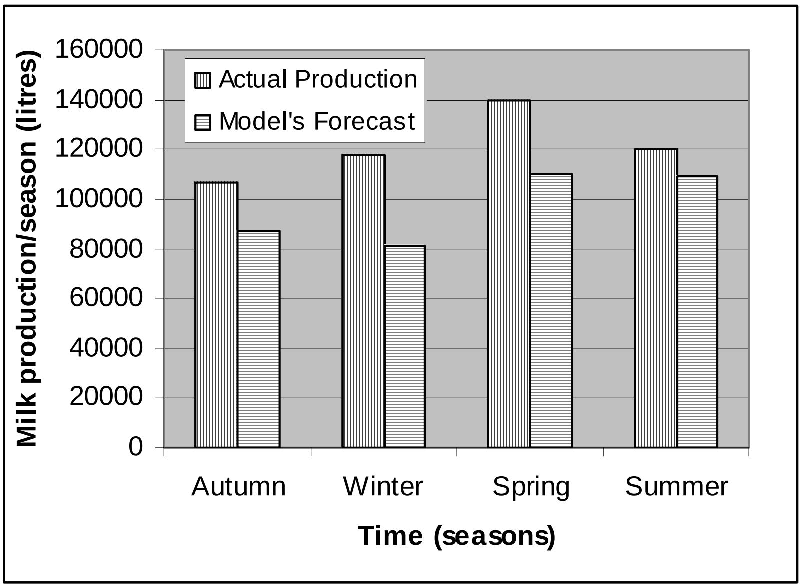
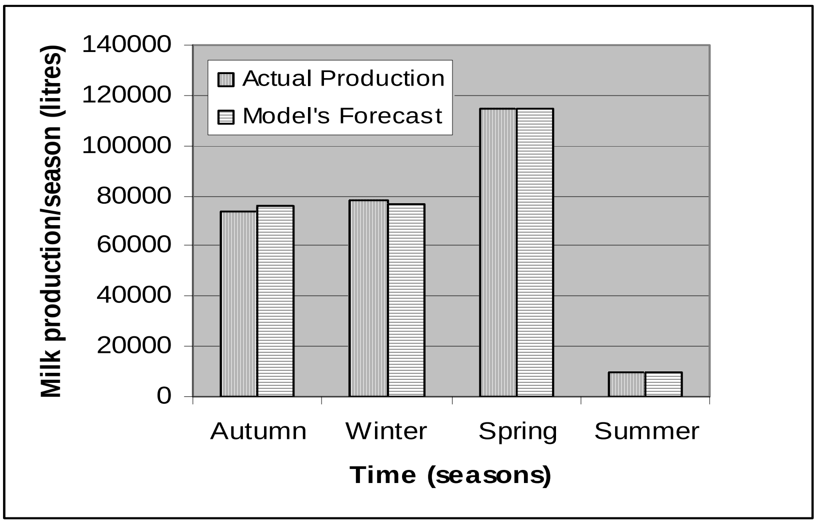


Figure 1: Total milk production per season from 1990 to 2002. Model's predictions before silage and forecasts after silage compared with actual production

Time series forecasting is useful in evaluating time trends on farms because it follows the natural progression of change. It has been used to forecast agricultural commodity prices (Harris & Leuthold, 1985) and returns on livestock production (Boyle, 1981). In most of the cases cited here, the Box-Jenkins ARIMA approach was used (Box & Jenkins, 1976). In this study, a decomposition approach was used, decomposing the series into trend, seasonal fluctuations and random error. This technique was used because it is easy to interpret and allowed a detailed assessment of seasonal effects (O'Donovan, 1983). The methodology used here is a variation of the intervention analysis technique proposed by Box and Tiao (1975). The technique has been used to evaluate the impact of abrupt changes in modelling and monitoring of a biological time series, including monitoring of renal transplant (Smith & West, 1983) and the ventilatory response of fish to the exposure to sub-lethal amounts of zinc sulphate toxicant solution (Thompson *et al*, 1982). The Box and Tiao (1975) method requires an *a prior* decision as to the effect of the intervention in order to develop a model of expected response. In the method used here the prediction model is developed from historical data on the assumption that no intervention occurs. The Box and Tiao (1975) model assesses the significance of the intervention by determining how closely the observed data fit the predicted, whereas in the present study significance of the intervention is established if the observed data are significantly different from the prediction. This technique has proved useful in this study in monitoring a major change in a farming system.



2a) Before silage - average milk production in each season from the model's predictions and actual production



2b) After silage - average milk production in each season from the model's forecasts and actual yield

Figure 2: The effect of maize silage on the seasonal pattern of milk production

Methods used in the past for evaluating on-farm performance have often used multiple regression techniques. These studies have measured relationships between input resources and output (Rayner & Young, 1962; Rees *et al*, 1972; Davison, 1988). Multiple regression techniques successfully interpreted data collected from farms and were able to explain the major input components and relate them to output. However, they are not able to make forecasts of future production as they do not interpret data relative to time. Another limitation of regression analysis is the inability to handle a major change in management during the study period.

Other methods of evaluation have included the Markov chain approach and Fourier series type models. The Markov chain approach has been suggested as an alternative to regression in analysis of crop yields, but at this point is considered too specific for general use in forecasting (Matis *et al*, 1985). Cook and Stevenson (1980) demonstrated the use of a Fourier-series-type model to determine the underlying trends, seasonal variation and periodicity of a time series of the prices on the principal wholesale markets in England and Wales for fresh mushrooms. They compared the time series from one period (1963-67) with another (1968-73) and no forecasts were made.

The time series analysis technique was able to forecast production trends and seasonal fluctuations. An estimate of the increase or decrease in production on a whole farm was obtained by comparing these forecasts with actual production. In this study, it was concluded that the introduction of maize silage to this dairy farm feed programme significantly increased milk production.

The significance of this approach is its ability to quantify the effect of changes in a farming system due to the introduction of a new technology. It could have applications in evaluating new technologies and assist in assessing the costs and the benefits to a farming enterprise. The net effects of these benefits can be calculated and used to convince farmers of the benefits of adoption of the technology.

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