Impacts of extreme climatic conditions on sugar cane production in northeastern Australia

I. KUHNEL
Climatic Impacts Centre, Macquarie University, North Ryde, New South Wales, Australia 2109

Abstract The impacts of anomalous climatic conditions, namely those of El Nino-Southern Oscillation (ENSO), on sugar cane production in northeastern Australia are examined. The results suggest that the influence of the ENSO signal varies regionally and the Southern Oscillation Index (SOI) is only of limited value for prediction of overall yields. However, for individual mills in the northern districts (where the correlations reach the value of -0.7 during the spring months), this index alone might be a useful indicator of following yields. The ENSO signal is accompanied by three major periodicities of the annual sugar cane yield data at 2-3, 7 and 10 years. The first two periods can be linked to frequencies often associated with the Quasi-Biennial Oscillation and ENSO itself.

INTRODUCTION

For Australia, and especially for Queensland (northeastern part of the Australian continent, see Fig. 1), sugar cane is the most economically important crop. Grown in a narrow coastal strip, which stretches from approximately 15 to 30 degrees south, the sugar cane crop thrives in the generally favourable mean rainfall and temperature conditions (above 1000 mm and 15°C, respectively) found here. Despite these overall favourable mean climatic conditions, the climate in this region displays large seasonal and inter-annual variability, a pattern often reflected in sugar cane yields. A large proportion of this climatic variability can be attributed to the phenomenon known as El Nino-Southern Oscillation (ENSO). This ocean-atmosphere coupled phenomenon shows an especially strong signal over the Australo-Indonesian region and the Pacific ocean (e.g. Ropelewski & Halpert, 1987, Allan, 1988). In its cold (warm) phase ENSO can lead to anomalously high (low) precipitation and a higher (lower) number of tropical cyclones over northeastern Australia (e.g. McBride & Nicholls, 1983, Evans, 1990) and can have a negative impact on the local sugar cane production.

In the past few years several attempts have been made to assess the impacts of ENSO on sugar cane production. Possible links between expected crop yields and various climatic variables have been examined. Recent studies by Russell (1990, 1991) have established the relationship between several climatological variables and seasonal rainfall at a few selected stations in the sugar growing area. Similarly, Wegener et al. (1988) made an attempt to predict sugar cane yields in the Australian region by using their AUSCANE model. However, these studies only concentrated on the yield conditions at a few selected stations, or on the regional analysis of rainfall rather than the regional analysis of sugar cane yield.
The main goal of this study is an extension of previous work and a detailed large-scale analysis of sugar cane yields with respect to climatological, biological and socio-economic impacts. This paper concentrates on the description of the impacts of climate on sugar cane, in particular the strength and periodicity of the ENSO signal.
DATA AND METHODOLOGY

The sugar production data used in this study consisted of annual crop yield figures (tonnes per hectare) for 27 Queensland mills (Fig. 1) for the period 1950-1989. As shown on the example of the Babinda mill (Fig. 2a), the data sets displayed a relatively strong long-term trend, which had to be removed prior to any analysis. This has been accomplished by subtracting a 5-year moving average from the actual annual production figures. In this way the original data sets (for 27 mills) have been de-trended and new time series of residuals have been created (Fig. 2b).

Similarly to the time series shown in Fig. 2b, the majority of de-trended data sets display strong fluctuations which appear to occur in more or less regular intervals. By using a Fourier analysis (supplied by the International Mathematical and Statistical Library [IMSL]) the data sets have been examined for dominant periodicities and the individual power spectra have been plotted (e.g. Fig. 2c).

Such an analysis can be justified by the fact that the most dominant proportion of the total variance of the yield data is likely to be explained by climatic conditions and not other factors, for example the crop cycle (Chardon, personal communication).

The Southern Oscillation Index (SOI), here defined as the standardised monthly pressure anomaly difference between Tahiti and Darwin, has been used for cross-correlations with the annual sugar cane yield residuals. The monthly stratified SOI data for the month of June has been used for simultaneous correlations (lag of 0
month, corresponding to the general start of sugar cane harvest in Queensland). The monthly stratified SOI data of the preceding months (May to July) has been used for lagged correlations (lag of -1 to -12 months). Only correlation coefficients (CCFs) above the 95% significance level (CCF of ±0.32 for a 40-year time series) are discussed.

DOMINANT PERIODICITIES

The most dominant periodicities occurring in the individual sugar cane yield data sets are summarized in Fig. 3a. These results reveal marked differences between the regimes in the northern, central and southern sugar cane growing areas of Queensland. As mentioned earlier these differences, which cannot be attributed to the crop cycle or other agricultural factors, are likely to reflect fluctuations in climatic conditions. As indicated by Fig. 3b, three major frequencies can be found in this

Fig. 3 (a) The most dominant periodicities of the sugar cane yield data for 27 mills in northern Queensland (mills in north-south order on the y-axis). (b) Typical power spectra of sugar cane yields for 3 major sugar cane districts (north - Mulgrave mill, central - Inkerman mill, south - Moreton mill).
area, showing periods of 2-3, 7 and 10 years, respectively.

The yields in the northern districts show a marked periodicity of 2-3 years resulting in a blue-noise type spectrum (i.e. an above normal harvest can be expected every 2-3 years, as shown in Fig. 3b on the example of Mulgrave mill). The notion of coloured noise will be explained in the sequel. This frequency is likely to correspond to the Quasi-Biennial Oscillation (QBO) of upper tropospheric winds in the tropics (e.g. Quiroz, 1983), which, in turn, partly influence the rainfall regime in northeastern Australia. This relationship has been indirectly confirmed by Russell (1991), who found a significant link between the QBO and the summer rainfall at two northern Queensland stations.

As shown on the example of the power spectrum for Inkerman mill (Fig. 3b), the 2-3 year period is still prominent in the central districts, although the most dominant frequency found there has a period of approximately 10 years. Extensive irrigation of this area (e.g. Chapman & Chardon, 1979) makes any conclusions about the influence of climatic signals more difficult. Nevertheless, the dominant peaks of the white-noise type spectrum for Inkerman (Fig. 3b) hint again at the influence of the QBO or/and ENSO, which tend to occur in 2-10 year intervals (e.g. Philander, 1983).

The QBO signal disappears further south and the red-noise type spectrum (for Moreton mill in Fig. 3b) only shows periodicities generally associated with the ENSO. The strength and significance of these relationships is currently being investigated in more detail.

The expressions "red-noise" and "blue-noise" spectrum are derived from the spectrum of light. Accordingly, the respective spectral curves are skewed towards the high (blue) or low (red) frequency spectral end (e.g. Mitchell et al., 1966).

**CORRELATIONS WITH THE SOUTHERN OSCILLATION INDEX**

Fig. 4 shows all significant CCFs between the annual (de-trended) sugar cane yield time series for all Queensland mills and the (monthly stratified) SOI. Simultaneous correlations (Lag-0 months) were obtained with the SOI for June and lagged correlations with the SOI for the 12 preceding months.

It is apparent that the influence of the ENSO signal varies from north to south. Whereas the northern and southern districts show a negative lagged relationship with the SOI, the yields in the central areas correlate positively with this index. As shown in Fig. 4, the strongest lagged correlations between these two variables (up to CCF of -0.7) can be found in the northern districts between lag -11 to -7 months. This implies that anomalously high rainfalls during the winter and spring months (July to November) are likely to be followed by lower-than-normal yields at the following harvest. One possible reason for this relationship might be an insufficient use of fertilisers, which cannot be used when conditions in winter and spring are too wet (Chardon, personal communication).

A similar, but somewhat weaker (CCFs of -0.5) relationship can be also found in the southern districts. These results suggest that, for individual mills, the SOI alone may be an useful indicator of expected yields. Nevertheless, for the prediction of total yields of larger areas, the SOI may have only a limited value.
This view is also supported by Russell et al. (1992), who propose the use of a combined SOI-SST (sea surface temperature) index for prediction of seasonal rainfall in four selected east Australian land regions. Their suggestion is understandable when the correlation results in the central sugar cane growing districts are examined (Fig. 4). In those areas positive significant correlations (in the order of +0.4) are obtained, which unlike the previously mentioned results, appear between lag -3 and -1 months (March to May before harvest). These results suggest that, in the central district, anomalously wet conditions few months prior to the harvest might improve the yield. Nevertheless, as mentioned previously, this area is heavily irrigated, which makes it more difficult to draw any conclusions at this stage.

**FUTURE WORK**

Results of the impacts of climate on sugar cane production in northeastern Australia, in particular the role of the ENSO, were discussed in this paper. The above analysis
revealed strong periodic fluctuations in sugar cane yields, which are likely to be closely linked with certain atmospheric phenomena, like the QBO and ENSO. A more detailed examination of the spatial and temporal patterns portrayed above is being currently undertaken using various other methods (e.g. use of the principal component analysis) and meteorological data sets (e.g. COADS, TABS).

The second stage of this study will analyze the impacts of major pests and diseases on sugar cane production. Such a study should explain an additional part of the total sugar cane yield variability, and explain certain production fluctuations which cannot be attributed to the influence of climate alone.

REFERENCES


