Seasonal climate forecasting in crop management

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Summary. Southern Oscillation Index (SOI) types representing both persistence and change in SOI values have been identified from a time series of the SOI. The associated rainfall probability values have been calculated for each month for a range of locations in eastern Australia. Simulation analysis for wheat at Goondiwindi identified large variability in future yield depending on whether the SOI type known at the time of planting represented rapid rise or rapid fall in value in the preceding months. Implications for gross margins and risk associated with management are described.

Introduction

Rainfall over much of eastern and northern Australia is strongly related to the El Nino and Southern Oscillation (ENSO) phenomena. The strong persistence of ENSO episodes allows seasonal forecasts to be made (2). The monthly SOI, which is calculated as the normalised difference in atmospheric pressure between Tahiti and Darwin (8), is a key indicator of ENSO (2) and correlates significantly with rainfall in the current month and, in some instances, with rainfall in subsequent months. Useful correlations occur from winter into summer and from late autumn into spring in eastern Australia (4). On a national scale the SOI has already proven useful *as* a direct indicator of crop yields. Australian yield of the summer crop, sorghum, can be predicted from the SOI well in advance of harvest (5).

Correlation (4) and isohyet maps (1), so far produced, have provided a benchmark indication of rainfall variability associated with different values of the SOI. Yet an examination of a history of the SOI reveals certain peaks and troughs in its values, as well as other periods in the life-cycle of the SOI, that may be referred to as SOI 'types'. The types may represent, not only the periods when the SOI is consistently positive or negative, but also when the SOI changes rapidly from a negative value to a positive value or from a positive value to a negative value. Previous studies have not investigated relationships of rainfall with change in SOI values over time. It has been suggested (6) that a change in SOI may be useful in a forecasting sense. Thus additional information relevant to climate forecasting is available by examining change in the SOI once relationships of SOI types with rainfall distributions have been identified.

Our objectives in this study were twofold. First, to objectively determine SOI types and examine their relationships with rainfall. Second, to evaluate the usefulness of skill in seasonal forecasting in crop management decision making. We focused on crop production systems in the northern wheat belt, but the approach is applicable generally.

SOI-rainfall relationships

Methods

To obtain a typology of the SOI, principal components analysis (PCA) and cluster analysis (CA) was applied to a SOI data set obtained from the Bureau of Meteorology. The data set was adjusted to contain the following variables: (i) current SOI value; (ii) lag one-month's SOI value; (iii) lag two-month's SOI value; (iv) difference between (i) and (ii); (v) difference between (ii) and (iii).

PCA was employed to remove correlation in the variables and detect underlying linear relationships in the data. Principal component scores were also derived and grouped according to various clustering algorithms provided, in this instance, by the SAS Statistical Packages. Thus, each running two-month period since 1882 was classified according to which SOI type it belonged.

Results

The cluster analysis identified five SOI types. Type 1 represents consistently negative SOI values where the mean value of the current SOI is -12.1. Type 2 represents consistently positive SOI values where the mean value of the current SOI is 9.5. Type 3 represents rapidly falling SOI values (from a mean value of 2.7, falling to a mean value of -10.0), while Type 4 represents rapidly rising SOI values (from a mean value of -4.4, rising to a mean value of 6.6). SOI values close to zero with little change over time are represented by Type 5.

Cumulative rainfall probability distributions for Goondiwindi for June for each SOI type are illustrated in Figure 1. Differences in rainfall distributions depending on whether the SOI type is Type 1 (consistently negative SOI) or Type 2 (consistently positive SOD are clearly evident. For example, the probability of exceeding 20 mm of rain is shown as 20 per cent during SOI Type 1, while the probability of exceeding 20 mm during SOI Type 2 is 67 per cent. Also evident is the high probability of receiving high rainfall during SOI Type 4 episodes; that is, periods when the SOI has rapidly risen, even though the SOI may not be highly positive. The long-term median for Goondiwindi for June is 29 mm, and the cumulative probability distribution closely resembles that for SOI Type 5.

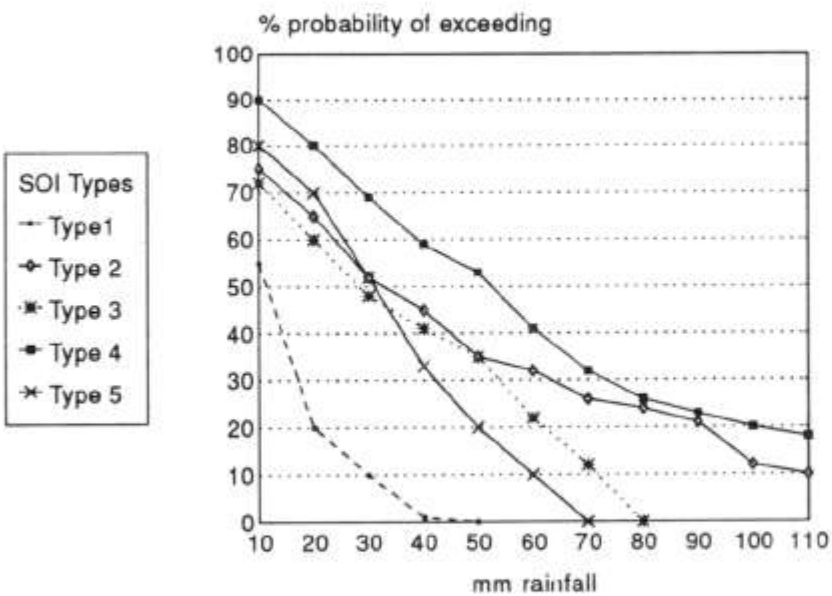

Figure 1. Rainfall probability distributions for each SOI type for Goondiwindi in June.

Crop management

Methods

The major management decisions affecting dryland crop production in north-east Australia are made when a planting opportunity occurs. An important decision is how much nitrogen to apply. At the time the decision is made, information available to the decision-maker includes the time of planting, the amount of stored soil water and nitrogen, subsequent rainfall and temperature probabilities (e.g. frost) based on long-term records, recent history of the SOI, and a seasonal rainfall forecast for the region. Expected yield can be estimated from simulation analyses using crop models for wheat with long-term weather data (3). Alternatives can be evaluated for expected profit and degree of risk, the final decision depending on the manager's attitude to the profit/risk trade-offs.

To examine the profit generated at various levels of N, and how this was affected by SOI type at the time of planting, we conducted a simulation analysis for wheat. A crop simulation model (3) was used to model a crop to be planted on 1 June each year at Goondiwindi on a soil with plant available water-holding capacity of 160 mm, containing 100 mm available water at planting. Cultivars of standard maturity type for the conditions and long-term daily rainfall and maximum and minimum temperature (96 years) were used in the simulation. The simulation was conducted assuming non-limiting N so that the simulated grain yield represented the environmental potential each year. The effect of N rate each year was predicted from potential yield for that year using a procedure derived by Woodruff (9 and Strong (7). The optimal N strategy over all years and for subsets of years associated with SOI types was determined by comparing average gross margin ($/ha) for each N rate (kg/ha). In this instance, SOI types were defined by using the change in SOI between February and May (6). The risk associated with different N strategies was examined by noting the probability of falling below a gross margin of $75/ha, which represents a reasonable value for fixed costs.

Results

The yield likelihood, with N non-limiting, (Fig. 2) shows the large variability in yield in these environments, with wheat yield ranging from 1300 to 5700 kg/ha over the 96 years simulated. In 50% of years, simulated yield exceeds 2100 kg/ha.

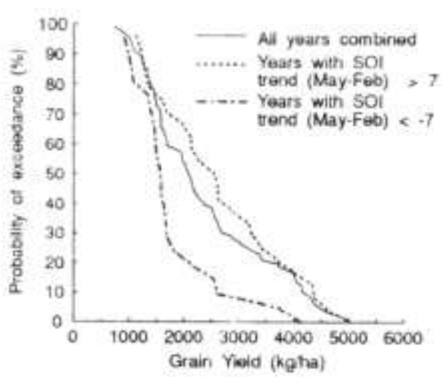

Figure 2. Grain yield likelihood.

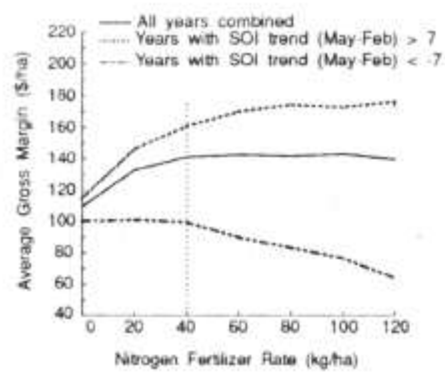

Figure 3. Gross margin *versus* N rate.

The yield likelihood changes substantially between SO1 type categories. At the 50% probability level, expected yield is about 500 kg/ha higher or lower than the mean for all years, depending on the SOI type. The maximum gross margin, for all years combined, was achieved with a N rate of 40 kg/ha (Fig. 3). For years in the two SOI type categories, gross margins are much higher or lower and maximum gross margins occur at different rates. Maximum gross margin changes from a N rate of 0 to 20 kg/ha when the SOI type represents rapidly falling SOI values to a N rate of 60 to 80 kg/ha when the SOI type represents rapidly rising SOI values. Modifying the N rate depending on the SOI type is therefore associated with significant changes in gross margin.

It is necessary to consider the risk associated with these decisions in addition to the average gross margin. The chance of obtaining a gross margin of less than $75/ha varied substantially with N rate and SOI phase. The chance was 25% over all years assuming a N rate of 40 kg/ha, but this increases to 40% if the same N rate is used in years where the SOI rapidly falls during February/May. In those years, the chance of obtaining less than $75/ha returns to 25% with no applied N, which corresponds with the rate for maximum gross margin in those years. In years when the SOI rises rapidly during February/May, risk is not increased greatly by increasing the N rate to 60 to 80 kg/ha, in order to obtain the higher gross margin at that rate in those years.

Discussion

Rainfall over much of eastern and northern Australia is strongly related to the El Nino and ENSO phenomenon, The monthly SOI, which is calculated from the normalised pressure difference between Tahiti and Darwin, is a key indicator of ENSO. An examination of the history of the SOI reveals peaks and troughs in its values. Using cluster analysis, we identified SOI types from the SOI time series. The types identified represented both persistence and change in SOI values. The monthly rainfall probability values associated with each SOI type were calculated for a range of locations. Rainfall probabilities differed greatly among SOI types. Using simulation analysis for wheat for one location in the northern wheat belt, we demonstrated that yield varied greatly depending on the SOI type known at the time of planting. This outcome had significant implications on nitrogen management, profitability, and risk. The approach we outline gives a specific example, but sets out a general approach to evaluating the usefulness of seasonal climate forecasting in crop management.

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