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An alternative method for assessing the value of the Southern Oscillation Index (SOI), including case studies of its value for crop management in the northern grainbelt of Australia

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Abstract. Previous studies have identified extra profit that could result from selecting management options according to particular phases of the Southern Oscillation Index (SOI). Those studies identified optimal decisions for each phase and the value of these decisions. However, this may have overestimated the value of SOI-based management through a lack of data for independent evaluation. This study compares the previous approach with a new method based on a simple sampling technique (analogous to *leave-one-out* cross validation) that estimates the range of future outcomes when independent validation data are not available. The new method gave much-improved estimates of the mean and variance of the value of the SOI for management. In studies involving wheat-growing in southern Queensland, this method indicated that management according to the April–May SOI phase yielded either small long-term increases (in 4 of 6 cases) or decreases (in 2 of 6 cases) in profit. There was considerable heterogeneity among phases, and the annual variance of the outcomes was large relative to the long-term average value in all 6 cases. Consequently, unless a strategy is applied long term (at least 10 years), there is a relatively high likelihood of higher or lower profit than for non-strategic management. The likelihood of increased and decreased short-term profit is approximately equal. In all 6 case studies, the long-term average economic value of SOI-adjusted management was less than, or equal to, the economic value of 1 mm of extra plant-available soil moisture at sowing.

Additional keywords: wheat, fertiliser, varieties, climate, forecast, skill.

Introduction

The 5 phases of the Southern Oscillation Index (SOI) are well known climate indicators, and a survey by Hayman and Alston (1999) indicated that 10% of wheat farmers in northern New South Wales always or often use climate forecasts in their N fertiliser decision-making. The phases have been shown to be useful through their associations with changes in the frequency distributions of rainfall amounts (Stone and Auliciems 1992) and frost incidence (Stone *et al.* 1996).

Studies of managing wheat crops according to the phases of the SOI have reported major benefits. Hammer *et al.* (1996) found 'Significant increase[s] in profit (up to 20%) and/or reduction in risk (up to 35%) were associated with tactical adjustment of crop management of N fertiliser or cultivar maturity'. Other studies of the phases have also found that they are valuable in making crop management decisions (Abawi *et al.* 1995; Meinke and Hammer 1995; Meinke and Stone 1997; Meinke *et al.* 1998).

However, although these studies identified improvements in the mean and distributions of outcomes from SOI-targetted management, these benefits were estimated from the same data used to identify the optimum management strategies. The outcomes are probably optimistic because the chosen management strategies are optimal for the data; but would not necessarily be so for new (independent) observations.

To realistically assess the benefits, if any, of SOI-targetted management for independent data, 2 methods of testing are available: (*i*) test new data as they arise on an annual basis, or (*ii*) use part of the data to develop an optimum management strategy and the remainder to assess its value. We have followed the latter strategy below because it avoids waiting several years for even a small amount of test data to accumulate.

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The aim of this study is to assess the economic value of SOI-targetted management strategies in the northern grainbelt when applied to observations not used in the derivation of those particular management strategies. Comparisons will be made between assessments of the value of the SOI based on the previous method and the new method, as well as benchmarking the value of the SOI in several case studies.

Methods

Six case studies are analysed to assess the value of the SOI-targetted management: selecting N fertiliser rates at Dalby in 2 cases with different levels of plant-available soil water (PAW) at sowing, selecting N fertiliser rates at St George in 3 cases with different levels of PAW, and a case of selecting wheat varieties at Dalby. Outcomes for the management options were simulated with a wheat model (Iwheat; Meinke *et al.* 1997) for the period 1888–1997. Soil nitrogen, soil moisture, and other factors were simulated in various modules within the Agricultural Production System Simulator (APSIM; McCown *et al.* 1996). Profit was calculated from the yield, protein content, and assumptions about costs and commodity prices (described below).

At Dalby, variety Hartog was simulated with either 60 or 90 cm depth of moisture in a black vertosol at sowing (plant-available water capacity, PAWC = 321 mm). Soil nitrate at sowing was 89 kg N/ha. Six fertiliser rates (0, 20, 40, 60, 80, and 100 kg N/ha) were simulated in each case. A third case at Dalby (Dalby variety) involved 3 varieties (Hartog and 2 longer season varieties, with 90 cm depth of wet soil and 40 kg N/ha of fertiliser), and simulation of frost by the method of Hammer *et al.* (1996). At St George, 3 cases (St George 60, 90, and 120) involved sowing with 60, 90, or 120 cm of wet grey vertosol (PAWC = 215 mm). Soil nitrate equal to 59 kg N/ha and 3 rates of fertiliser (0, 20, and 40 kg N/ha) were simulated in each case.

The simulated sowing date was 1 June. Profits (AU$/ha.year) were calculated from the following data. Fertiliser cost $1.00 per kg N, and for rates of 40 kg N/ha and higher, an extra pre-plant application cost of $10/ha was included. Wheat prices, net on-farm, varied with grain protein: <10% = $120/t, ≥10% and <11.5% = $150/t, ≥11.5% and <13% = $175/t, and ≥13% = $200/t. Annual non-fertiliser variable and fixed costs were assumed to be $100/ha each for St George, and $150/ha and $200/ha, respectively, for Dalby.

In each month of each year, the SOI can be in any 1 of 5 phase states: 1, consistently negative; 2, consistently positive; 3, rapidly falling; 4, rapidly rising; 5, near zero (Stone and Auliciems 1992). This study assessed the phase states in both March–April and April–May of each year, initially concentrating on April–May because it is considered a better indicator of subsequent seasonal conditions (Roger Stone, pers. comm.).

APSIM was used to estimate yield, protein, and profit for each N rate or variety in each year. The economic value of SOI-targetted management, over and above the most profitable long-term ('fixed') N rate or variety, was calculated from these data by the following 2 separate methods.

(*1*) Fitting values. The annual value ($/ha.year) of adjusting the fertiliser rate or variety was assessed against the best of the fixed management strategies (i.e. across all 5 phases). The annual value is the extra profit for each year (1888–1997) from using the best strategy for each phase instead of the fixed strategy. Best management strategies were taken to be the ones with the highest average profit for each phase. We calculate an empirical distribution function (EDF) from these profit values, that are referred to subsequently as the **fitted** outcomes (**F**).

(*2*) Predicting values: where the SOI-targetted management strategy is determined for all but one year, then it is valued by application to that one year. The process is repeated for all years (1888–1997), then an EDF of the profit values is calculated in the same way as the fitted outcomes. This is analogous to the leave-one-out method of cross-validation (Efron and Tibshirani 1993, Ch. 17). These are subsequently referred to as **predicted** values (**P**) because the predictors are distinct from the predictand.

To explore the range of potential outcomes that may occur by simple chance from the 2 methods in the 6 examples studied, 100 sets of randomly selected phase labels (i.e. dummy labels) were valued. The resultant EDFs of profit from random number-targetted management are denoted R_f and R_p below (fitted and predicted values, respectively). Of course, sound methods of valuing SOI-targetted management will not attribute value to management strategies based on random numbers (when compared with the optimal long-term strategy). Methods that over-value strategic management, such as those calculating economic benefits from random number-targetted management, are often affected by what is known as *artificial skill*. Methods that segregate the predictors and outcomes (such as our method P, above) may be less affected by artificial skill than methods that do not (such as the previous method F, above).

Results

The EDFs of the fitted (F) and predicted (P) outcomes for the April–May SOI phase vary in central tendency, range, and skewness between phases for all cases except St George 120 (Fig. 1). Not surprisingly, there is also considerable variation between cases in the central tendency, range, and skewness of outcomes. Estimates of the average value of each phase for the data in Fig. 1 are given in Table 1. The value of the phases varies widely between examples and is not always positive. The estimated long-term values are consistent between fitted and predicted outcomes for phase 1 in all cases, and for various other combinations of cases and phases. Where the distributions differ in range and/or skewness there is a general tendency for the average value of the fitted outcomes to be optimistic relative to the predicted values (Fig. 1 and Table 1).

In all cases the average fitted values are positive in all phases, and range from $1.10/ha (St George 120) to $14.00/ha (Dalby Variety) (Table 1). The average predicted values include losses in some phases, and the averages are considerably lower (–$15.10 to $5.50), with economic losses for both Dalby 90 and St George 90 examples.

The March–April SOI phases are acknowledged as having less predictive skill with respect to rainfall amounts in the subsequent cropping seasons (Roger Stone, pers. comm.). Results for the predicted values are consistent with this principle; they indicate that the March–April phase is less valuable than the April–May phase. Using these phases was more profitable than fixed management in only 1 of the 6 cases (St George 60), whereas the phases in April–May produce an increase in overall profit in 4 of the 6 cases, ranging up to $5.50/ha.year (Table 1). However, fitted values for the March–April phases compared favourably with the April–May phases in 3 of these cases (Dalby variety selection, St George 60, and St George 90, data not shown).

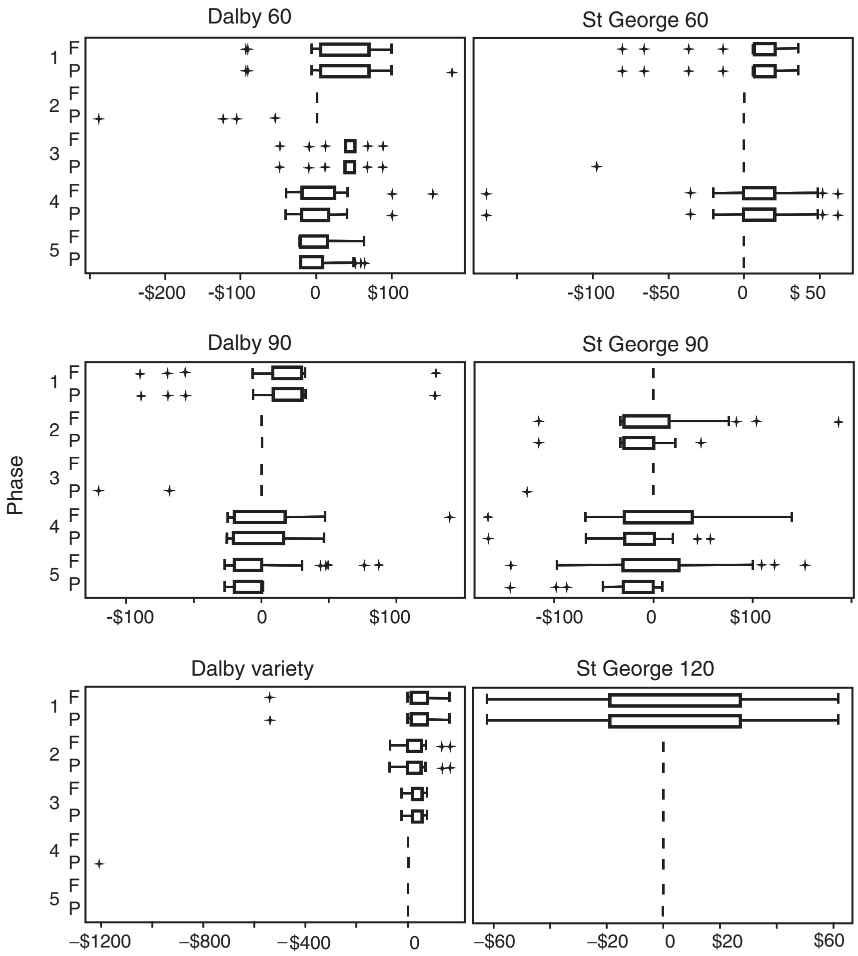

Fig. 1. Box-whisker plots of the distributions of fitted (F) and predicted (P) outcomes (*X*-axis, AU$/ha). AU$0/ha indicates an outcome equal to the best fixed management strategy. The box, whiskers, and stars represent the mid quartiles (lowest 25% to highest 75% of values), the mid 95% of values, and outliers, respectively. Different scales are used for each case. Note that differences between the outliers account for the main differences between the pairs of distributions (F and P) in several instances.

Table 1. The mean value (AU$/ha.year) of the fitted (F) and predicted (P) outcomes of SOI-based management of N fertiliser rates or wheat varieties

Management was based on the April–May phase of the SOI. Values rounded to nearest $0.10/ha.year

Case study	Method	SOI phase 1	2	3	4	5	Total (all years)
Dalby 60 cm of wet soil	Fitted	37.10	0.00	38.60	5.80	5.10	13.70
	Predicted	37.10	–24.60	38.60	–0.20	–1.00	5.50
Dalby 90 cm of wet soil	Fitted	14.40	0.00	0.00	3.30	0.40	3.20
	Predicted	14.40	0.00	–13.40	–2.10	–11.90	–3.00
Dalby Variety	Fitted	25.30	27.00	33.10	0.00	0.00	14.00
	Predicted	25.30	27.00	33.10	–46.40	0.00	3.00
St George 60 cm of wet soil	Fitted	4.90	0.00	0.00	5.60	0.00	2.10
	Predicted	4.90	0.00	–6.90	5.60	0.00	1.20
St George 90 cm of wet soil	Fitted	0.00	3.20	0.00	2.40	0.50	1.40
	Predicted	0.00	–16.50	–9.10	–18.70	–23.10	–15.10
St George 120 cm of wet soil	Fitted	6.50	0.00	0.00	0.00	0.00	1.10
	Predicted	6.50	0.00	0.00	0.00	0.00	1.10
No. of years		18	23	14	26	29	110

All changes in profit were small, especially in relation to the annual variability. The annual sequence of predicted outcomes (P, $/ha) for the phases in April–May for Dalby 60 is shown in Fig. 2. This case, where SOI-adjustments were most profitable (Table 1), demonstrates the occurrence of both frequent annual losses (41% of years) and gains (42% of years). The overall gain is strongly influenced by the benefits of phase 1 and phase 3 years (Fig. 1). The small size of most of the losses is because they represent expenditure on fertiliser that does not result in a yield or protein/price response (commonly –$20/ha for 20 kg N/ha applied without economic benefit). However, the long-term average increase in profit of $5.50/ha.year is obviously small relative to the annual variability (Fig. 2). Short-term profit (2–20 years) from targetted management will be strongly affected by annual variability in cases such as this. For example, some 10-year totals of the values shown in Fig. 2 are: 1900–09, $93/ha; 1910–19, –$59/ha; 1920–29, –$204/ha; 1930–39, –$5/ha; 1940–49, $217/ha. The highest 10-year total in this case was $247/ha from 1972–81 and the lowest –$328/ha from 1912–21.

There was considerable variability in predicted values of the phases for managing N fertiliser decision-making at St George. An overall loss of $15.10/ha.year was calculated for the St George 90 case using the April–May SOI. This value was due to less profitable decisions in 47% of years and a high average cost of these losses. SOI-adjusted management increased profit in only 9% of years in this case, which was the only one where management targetted at phase 1 was economically neutral. Economic benefits in the cases with 60 cm or 120 cm of wet soil were also modest, especially in relation to the annual variability. All phases except 1 were economically neutral at St George 120.

The results for the random phases (R_f and R_p, Fig. 3) show that the average estimated returns are consistently lower and the variance higher for the predicted values. The differences are an indication of the potential for artificial skill in these 6 cases if SOI-targetted management was assessed in the absence of independent validation data.

Discussion

When using the predicted (P) method, the variability between years within a phase is sufficient that when each individual year is excluded from the data, a diversity of 'optimum' management strategies appears within each phase. Not surprisingly, this leads to many annual outcomes that are less profitable than those obtained from a single strategy optimised over all years in each SOI phase, as in the fitted method (F). The difference in all-years value across the cases between the fitted and predicted outcomes ranged from $0 to –$16.50/ha.year. Although it would be unwise to generalise, the cases presented in this study indicate that the value of managing according to the SOI phases may frequently be less than previously estimated, due to the bias in the previous method where strategies were fitted to the data and then valued without independent data.

When viewed across all phases there seems little or no extra profit to be made from SOI-targetted management. However, this simplification may obscure potential benefits that seem to exist in specific phases and cases. For example, targetted management for phase 1 was neutral or profitable in all 6 cases studied here. Although this result is by no

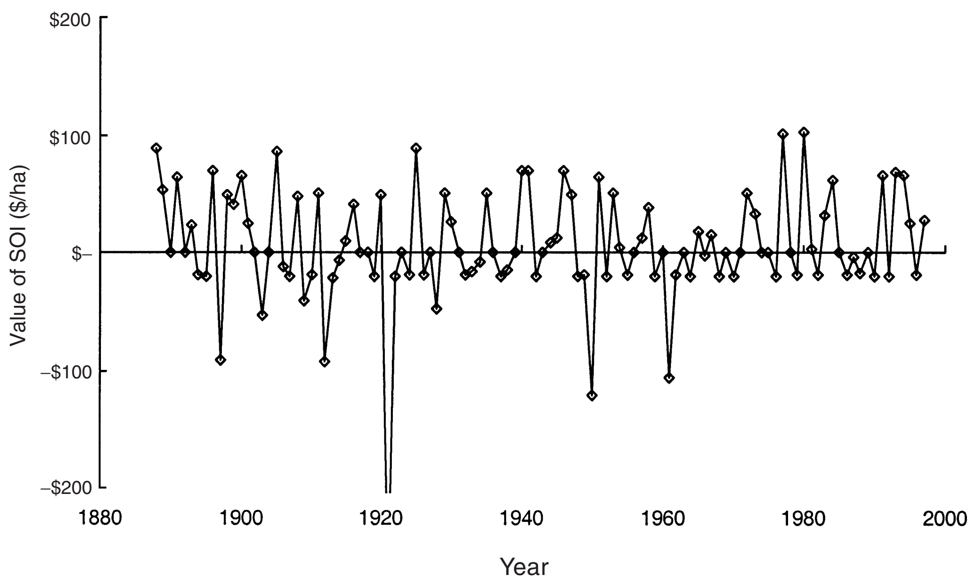

Fig. 2. The predicted value (extra profit, AU$/ha) of the SOI phases for N fertiliser management in wheat at Dalby (60 cm of wet soil at sowing).

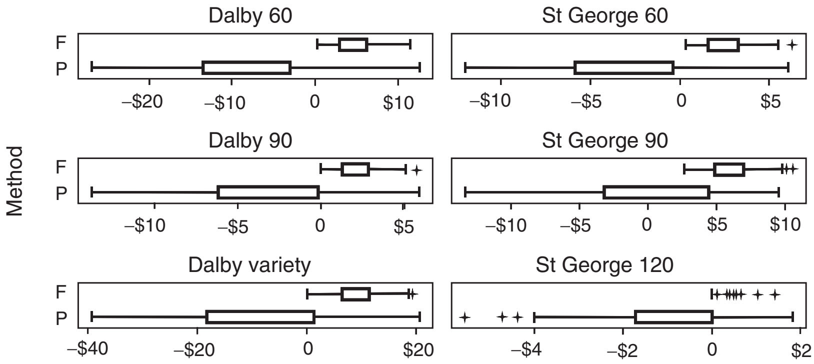

Fig. 3. Box-whisker plots of the distributions of fitted (F) and predicted (P) outcomes for dummy (random) SOI phases in the 6 case studies.

means definitive, one response to this information could be to adopt an SOI-based strategy for phase 1 years, and adopt a neutral or more conservative approach otherwise.

The positive fitted values (F) attributed to intrinsically valueless random numbers (Fig. 3) suggest that the methods used in previous studies resulted in overestimates of the value of SOI-targetted management. In all 6 cases, that method attributed positive economic values to numerous sets of random numbers. However, although this casts considerable doubt on the appropriateness of the method used in previous studies, this result (on its own) does not imply that there is no value in the phases of the SOI for crop management. In fact the average results for some of the case studies (Table 1) tend to fall in the positive tail of the distributions in Fig. 3, providing some evidence of forecasting skill above that contained in random numbers. For example, for Dalby 60, the mean of F = \$13.70/ha.year and the mean of P = \$5.50/ha.year, both of which are in the top quartile of the distribution of outcomes for sets of random numbers. Examination of Table 1 and Fig. 1 suggests that SOI-targetted management in phase 1 is largely responsible for benefits over and above those of random numbers.

What are the sources of the differences between the fitted and predicted values? Fig. 1 shows that the central ranges of values of F and P are usually similar. The differences in the mean values of F and P (Table 1) are mainly caused by combinations of (*i*) failing to make some of the highly profitable choices of F (e.g. St George 90, phases 2, 4, and 5) and (*ii*) making some large losses under P (e.g. Dalby variety, phase 4). These differences between F and P hinge on the differences in the datasets used and the consequences of different choices. Although the rule-making datasets differ only by a single year, the differences were sometimes considerable because of the small number of years and high variability in each SOI category (Table 1). The consequences of choice also varied considerably between the cases. For example, choice could be very important in the Dalby variety case, where a poor choice of variety could lead to frost and a total loss of yield (see the negative outlier in phase 4, Dalby variety, Fig. 1). Overall, in the 6 cases studied, the associations between the SOI phases and management options are not sufficiently uniform to consistently make gains or avoid losses. Given the variability of the outcomes, there is a relatively high likelihood, and near equal chance, of either substantial economic gains or losses from tactical management in the short term, as shown for the Dalby 60 case in Fig. 2.

To gauge the relative merits of managing fertiliser rates and varieties according to the SOI, it can be compared with the value of other management changes or resources. In the northern grainbelt, good fallow management is important to accumulate and conserve soil moisture. Data from these case studies can be used to show that an extra mm of soil moisture available at sowing is worth about \$5/ha.year of extra profit at Dalby and St George. For example, the average difference in profit between Dalby with 60 cm of wet soil and 90 cm of wet soil is \$366/ha.year (at 40 kg fertiliser N/ha.year). The difference in PAW at sowing is 69 mm, so the return from extra PAW in this example is \$5.30/ha.year.mm. Comparison with the most profitable cases of phase-targetted management in Table 1 shows that the benefits are approximately equivalent to storing 1 mm and 0.25 mm of PAW at sowing at Dalby and St George, respectively.

From a farmer perspective, it could not be recommended to use the SOI phases to adjust management in cases such as those examined here.

Conclusions

Previous studies have identified structure and economic value in the distribution of outcomes from SOI-targetted management, but may have overestimated the value of tactical management because of the lack of independent evaluation data. The method described here attempts to overcome this by evaluating apparently optimal management strategies on years not included in the development of the rules. This approach recognises the heterogeneity within phases and that the (apparently) optimal rule for a given phase may change with the composition of the phase.

Although the results show that SOI-targetted management could not be recommended in these cases overall, there were also indications that a relatively reliable benefit may be obtained from altering N fertiliser and variety management in years with an April–May SOI phase of 1 (consistently negative). However, the relationship requires further investigation and wider evaluation.

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