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Use of El Niño climate forecasts in Australia

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The linking of seasonal climate forecasting to agricultural models and decision support tools is receiving considerable attention in Australia. The emphasis on developing these linkages is justified given the importance of agriculture to export earnings and to the Australian economy, and given the extreme variability of weather patterns, particularly of rainfall, in the agricultural areas of Australia.

The main development that has occurred over the last decade in accounting for weather in commodity analyses, has been the linking of improved meteorological information into farm decision and agricultural models. ABARE has drawn on this work in developing its own systems for forecasting both crop and livestock yields.

Although there have been substantial advances in incorporating El Niño Southern Oscillation information into production forecasts, much still needs to be done. Recent experience has shown that significant gains are possible using a cross disciplinary approach to the task.

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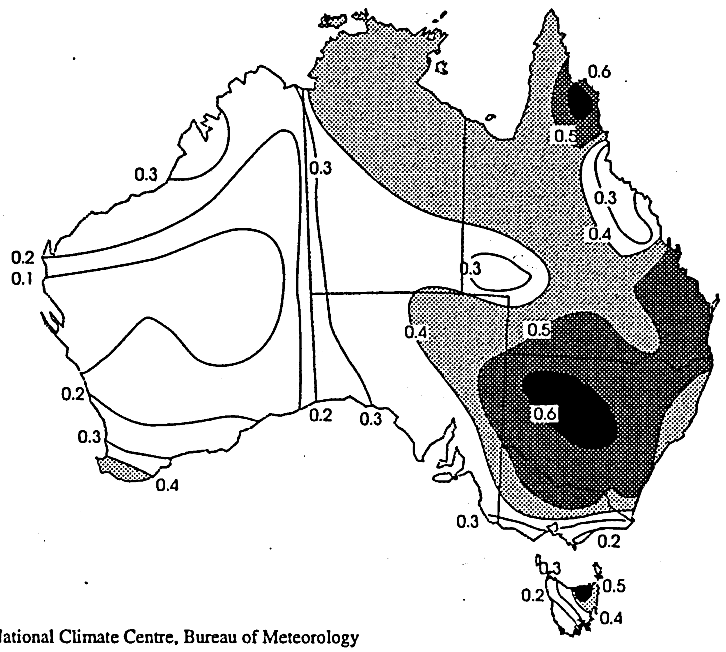
Introduction

Inter and intra year changes in weather affect expectations about agricultural production as well as final production outcomes. Climate variability is therefore an important factor in agricultural price formation and also affects year to year patterns of world trade — especially of crop products.

In Australia, rainfall variations are unarguably the main contributor to changes in crop yields and livestock productivity between one year and another. These changes are of major economic significance — for farmers and agribusiness industries, as well as for the national economy as agriculture accounts for around a quarter of Australia's total merchandise exports. In 1994-95, for example, the gross value of Australian rural production is estimated to have been reduced by 10 per cent as a result of drought and the value of farm exports by 12 per cent (Hogan, Woffenden, Hanslow and Zheng 1995). In the same study, it was estimated that the 1994-95 drought would reduce Australia's economic growth by up to 1.1 percentage points in that year and by 0.4 percentage points in the following year.

Across the eastern and northern areas of the Australian continent, a significant proportion of the rainfall variability is linked to the El Niño Southern Oscillation (ENSO) phenomenon (figure 1). The ENSO, as measured by the Southern Oscillation Index (SOI) — which is the normalised difference in atmospheric pressures between the northern Australian city of Darwin and Tahiti in the South Pacific Ocean — is strongly associated with the periodic large scale droughts that occur throughout Australia. When an ENSO

Figure 1: **Correlation between annual rainfall and the SOI**



Source: National Climate Centre, Bureau of Meteorology episode is active, rainfall over these parts of Australia tends to be suppressed during (the southern hemisphere) winter, spring and summer.

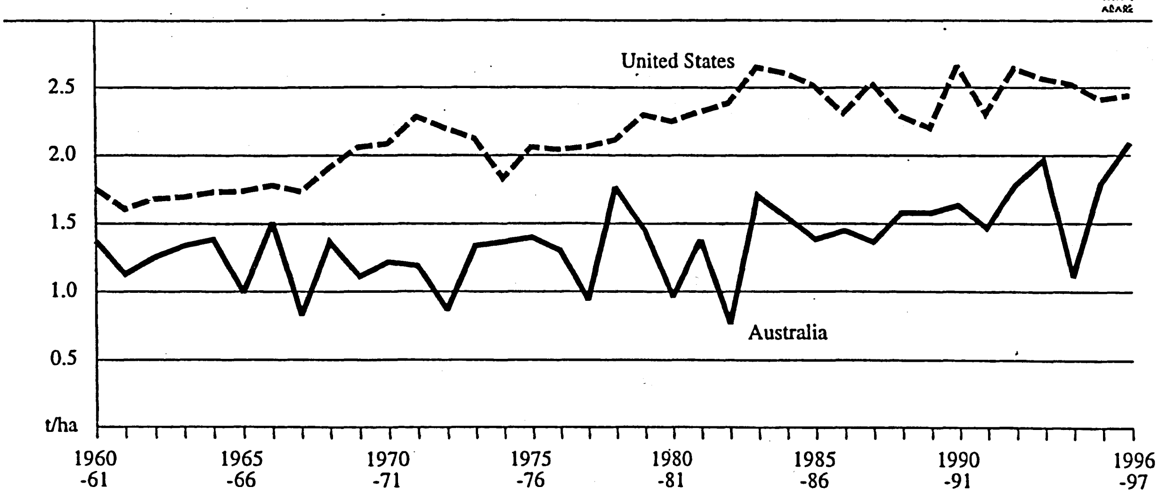
By incorporating improved forecasts of weather patterns into agricultural commodity production models, the reliability of market forecasts may well be improved. Since ABARE releases agricultural production, price and export forecasts on a regular basis, it has a keen interest in using weather information to improve the quality and reliability of its output. The discussion in this paper provides a brief overview of research into the links between climate and agricultural production, as well as an outline of ABARE's own efforts to incorporate weather into its commodity forecasts.

Climate variability and crop yields

As Australia is a large agricultural exporter, supplying around 15 per cent of world wheat exports, over 90 per cent of world wool exports and a quarter of world beef exports, climate induced variations in Australian production can (and do) affect world markets. The relatively high degree of year to year variability in rainfall in the main agricultural producing regions is the main contributor to short term changes in agricultural output in Australia.

The substantial swings in annual rainfall, and resulting variability in agricultural production is most evident for crops. Crop yields are more variable in Australia than in other major producing countries such as the United States (figure 2). The coefficient of variation of detrended Australian wheat yields, which measures the degree to which yields fluctuate from trend, was 19 per cent for the period 1960-61 to 1996-97. In the case of the United States, the coefficient of variation of detrended wheat yields was 7 per cent for the same time period. A large part of the difference can be attributed to higher year to year variability of rainfall in the main crop producing regions of Australia relative to equivalent US regions.

Figure 2: Wheat yields in Australia and United States



A large amount of work establishing the link between meteorological events, particularly rainfall, and agricultural yields was carried out in North America during the 1960s and 1970s. In particular the works of Cowling and Carter, Shaw, Fawcett and Carter and the National Oceanographic Association of America were critical in the linking of rainfall and agricultural yields (Fisher 1978). In recent years, the United States has been at the forefront of climate prediction, especially in the development and testing of global circulation models (Keshavamurty 1983; Penland and Magorian 1992; Kumar, Hoerling, Leetma and Sardeshmukh 1996)

Reflecting the importance of interseasonal rainfall variation to Australian agriculture, there is a considerable body of research (mainly by meteorologists, but with some input from agricultural economists) on establishing quantitative links between climate information and crop and livestock production. The basis for much of the advances which have occurred has been the identification of relationships that link the Southern Oscillation Index (SOI) to rainfall. This has enabled significant progress to be made over the past decade in using the SOI and rainfall variables in crop forecasting models (see Nicholls 1986; Stephens, Walker and Lyons 1994; and Stone, Hammer and Abawi 1995).

In one particular study (Stone and Auliciems 1992), past measurements of the SOI were grouped into five distinct phases: phase 1 – consistently negative (dry); phase 2 – consistently positive (wet); phase 3 – rapidly falling (dry); phase 4 – rapidly rising (wet); and phase 5 – close to zero and stable (normal). The results of this study have proven to be particularly valuable in enabling researchers to improve their ability to use ENSO information to predict rainfall and yields. Stone and Auliciems also observed that the state of the Southern Oscillation — as measured by the SOI — often changes into a phase (wet, dry, normal) in the Australian autumn (March through May) and that it generally persists in this phase for the rest of the growing season. They established that rainfall during the subsequent crop growing season could generally be grouped into one of the above phases based on changes in the SOI in the autumn.

The analogue approach to forecasting

Using the approach developed by Stone and Auliciems, historical analogue data, such as rainfall or frost occurrence, can be analysed to find relationships between different ENSO phases at a regional level.

The advantage of this 'analogue' method is that it provides a timely means of developing probability distributions for various climatic variables in different regions. In the case of winter crops, which in Australia are mostly planted in May and June, an important feature of the relationship between the ENSO and rainfall is that the transition between El Niño and the opposite weather feature of La Niña generally occurs between January and April. If the SOI is negative in autumn, there is a higher probability of it remaining negative until the following autumn. Such a pattern was observed in 1997-98 when the SOI moved strongly negative in March–April–May 1997 (figure 3). Rainfall in eastern Australia was well below average in the winter, spring and summer of 1997-98. A rapid rise in the SOI in autumn means there is a higher probability that the following summer median rainfall will be above normal.

The main disadvantage with the analogue approach is that the probability distributions associated with each phase are quite large. This means that the reliability of the method is relatively weak when used for Australia as a whole. However, in some regions such as Queensland and northern New South Wales the relationship between rainfall and the different SOI phases is quite distinct and therefore results in more accurate yield forecasts.

The relationship of winter rainfall (June–August) in the northern New South Wales grain growing areas and the different SOI phases is shown in figure 4. The winter rainfall for all

Figure 3: **Monthly and six month moving SOI phase in July**

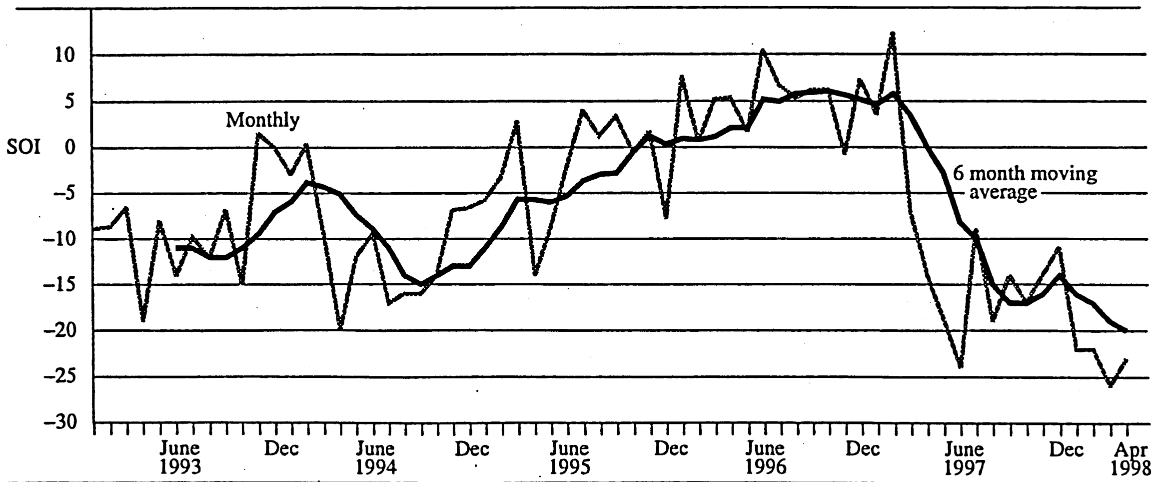
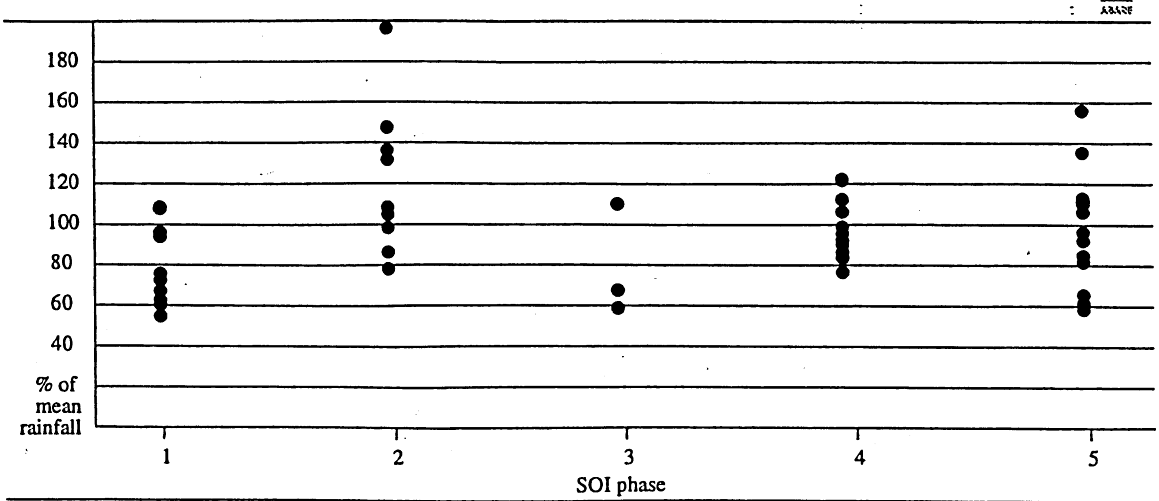


Figure 4: **Rain in northern New South Wales and SOI phase in July**



years from 1930 has been categorised into one of the five phases, based on the state of the SOI in July of that year. The rainfall received for each winter is expressed as a percentage of the median winter rainfall for this area over the period 1930 to 1996. In phase 1 years, rainfall is predominantly below the mean of recorded winter rainfall, while rainfall in most phase 2 years is above the mean. While phase 3 has only three observations, two are significantly below the mean rainfall, while rainfall in phase 4 and 5 years tend to be centred around the mean rainfall.

An added problem with the analogue approach is that for a given ENSO phase, each region maintains the same probability distribution. This means that this approach has no way of determining which regions will be most affected by different ENSO events. For example, the Southern Oscillation Index was very negative in 1982 and in 1997. In 1982, Australia suffered an extensive and widespread drought, yet in 1997, while rainfall was below average, most regions received more than twice the rain recorded in 1982. For Papua New Guinea and Indonesia, the pattern was reversed, with below average rains received in 1982, but extremely below average rains in 1997.

Global circulation models

In response to the above problems, global circulation models are being developed to indicate the varying spatial effects of medium term climatic changes on yields (usually about 3 months). A defining characteristic of global circulation models (and a major disadvantage) is that they require large amounts of data.

The requirement for copious amounts of data means that there are significant time lags between when a relevant climatic event occurs, and when it is recorded, collated and available to be run in the various models. Apart from the delay in gathering and preparing data, global circulation models also take a large amount of time (normally weeks) to run.

The fact that the results of global circulation models are usually published as a composite (or ensemble) of different model results means there is a significant time delay before medium term forecasts based on global circulation models are released. Because the forecasts are usually a composite of different models, it is also difficult to come up with appropriate values for individual variables to use in agricultural production models.

Incorporating weather into ABARE forecasts

As the major agricultural commodity forecaster in Australia, ABARE has attempted (with varying degrees of success) to incorporate three month climate forecasts into both its crop and livestock production forecasting systems. The issues of seasonal climate variability and agricultural yield forecasting in the Australian context, and ABARE's approach to incorporating climate into its forecasts, are discussed in some depth in ABARE (1997).

ABARE crop forecasts

ABARE regularly prepares forecasts of area, production and yields for more than twenty winter and summer crops in each Australian state. Yield forecasts are published five times a year in the *Australian Crop Report.*

Until fairly recently, forecasts of yields by ABARE (and most other forecasters in Australia) have been based on a combination of discussions with people 'on the ground' and the use of in-house analysts' professional judgment of the significance of weekly and monthly rainfall data from the principal crop producing regions. Such forecasts have been subjective and, until well into the season, have usually assumed average yields. The advances (discussed in the preceding section) in improving climate based seasonal forecasting models means that ABARE is now able to incorporate model based approaches into its forecasting of crop yields.

The model used currently by ABARE in its crop forecasting work is based on a weighted rainfall index (WRI) wheat yield model developed by Stephens, Walker and Lyons (1994). This is similar to the method proposed by Doll (1967). The WRI model, uses rainfall in 45 major wheat growing districts across Australia. The index at the national level may be represented as:

$$WRI = \sum_{m=-3}^{11} \sum_{d=1}^{45} R_{md} * W_{md} * W_d$$

where:

d = district ($d = 1, \ldots, 45$)

m = month ($m = -3, \ldots, 11$) (where $m = 1$ is January of the prediction year)

R_{md} = rainfall during month m in district d

W_{md} = weight assigned for rainfall during month m in district d

W_d = proportion of national production contributed by district d.

Stephens, Hawker and Lyons (1994) found the WRI explained 87–92 per cent of the variability of wheat yield in the eastern states of Australia, and 67 per cent of the variability in Western Australia, using actual rainfall data for an entire year.

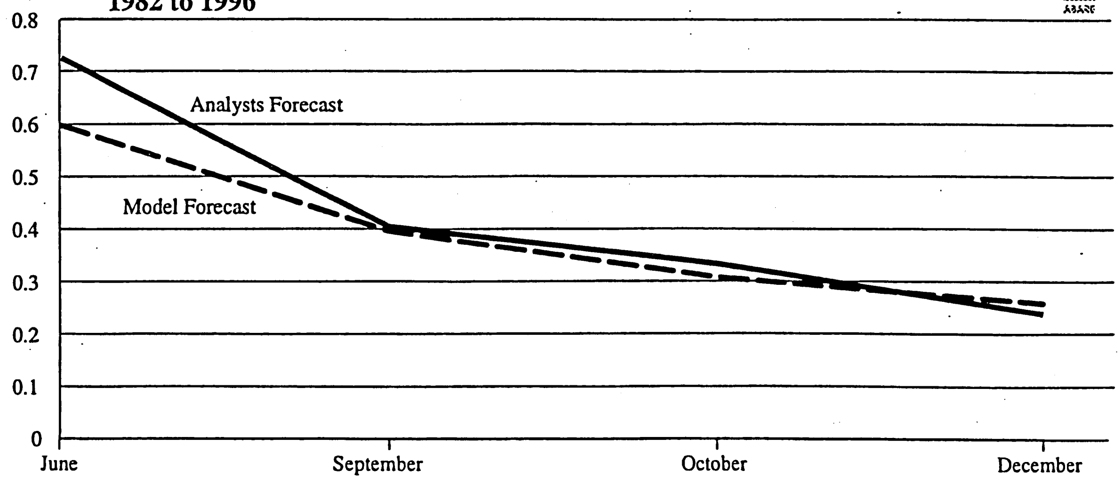
The ABARE version of the WRI model uses median rainfall for each SOI phase in each region as the basis for predicting state and national wheat yields. As the model incorporates actual rainfall data as it becomes available, it can generally forecast divergences from longer term average wheat yields on a regional basis earlier than other static models.

In order to illustrate the improvement in forecast accuracy for wheat, historical data have been used to simulate the results that this model would have given if used previously. These results were then compared with the forecasts published in the *Australian Crop Report* between 1982 and 1996. The new model was found to outperform the previous analyst based forecasting method early in the season, but the results from both approaches were much the same from spring onwards. This is illustrated in figure 5 for the state of New South Wales.

A significant shortcoming with the model, given that it is based on a yield/rainfall relationship, is that it cannot take account of such things as damage to crops from diseases, temperature extremes (including frosts), wind and hail, or pests. Furthermore, as the model uses monthly rainfall data, rain that falls near the beginning or end of a month can substantially change the model's yield estimate depending on which month the rain actually falls.

While the model is designed to account for the varying importance of rainfall in different months, it is not sufficiently sensitive to pick up the 'timeliness' factor with regard to rain occurring at critical periods in a crop's development. For example, during 1997-98 rainfall in many of the main winter crop growing areas of the eastern Australian states was well below normal (as much as 50 per cent below in some cases) during the crop growing period — yet wheat yields were approximately equal to their longer term detrended average. This apparently anomalous result occurred because good rains fell in most of the main cropping areas at an especially critical time (early spring) for the crops' development. The monthly rainfall data available to the model would, however, be consistent with significantly below average wheat yields in eastern Australia. Because factors such as the above are currently beyond the scope of the model to identify, when developing ABARE's published production forecasts, significant weighting is still attached to information about local conditions obtained from regional agronomists.

Figure 5: **Root mean square percent error of wheat yield forecasts for New South Wales, 1982 to 1996**



In forecasting yields of other winter grains crops, model estimates of wheat yield variations at a state level are used to adjust the longer run detrended yields for each crop. The adjustment takes into account the historical relationship between wheat yields and those of the other winter crops for each state. In the case of New South Wales, yields of barley and oats (the other major winter cereals) are relatively highly correlated with wheat yields (table 1). Barley and wheat yields are also highly correlated in Queensland. This approach to yield forecasting works well for barley and oats, but the results are not so encouraging where the yield correlations are low — such as for canola, safflower and linseed.

Table 1: **Correlations between detrended yields, 1951–95**

	Wheat and other winter grains	
	New South Wales	Queensland
Barley	0.90	0.90
Oats	0.90	na
Linseed	0.63	0.64
Safflower	0.18	0.50
Canola	0.53	na

na Not available.

ABARE livestock forecasting

Despite substantial efforts over the past 20 years or so (see ABARE 1997 for details), attempts to incorporate rainfall into livestock forecasting models has not been as successful as it has for crops. This lack of success reflects, in large part, the greater geographic diversity of livestock production in Australia; its continuous production process; and lower sensitivity to short term weather factors such as rainfall. The latter comes about because of the ability of producers to provide supplementary feed — including the movement of stock to regions with better pastures — during drought years.

The main research emphasis in the livestock area has been on forecasting wool yields (wool production per sheep shorn). The relationships between ENSO phases, pasture growth and wool yields, at both state and national levels have been investigated.

In undertaking research into wool yields and the effect of weather, a key consideration is the fact that virtually all sheep in Australia are grazed on pastures. This means that, even though wool production is not as rainfall sensitive as crops, for any given stocking rate, weather conditions will be the most important determinant of fodder availability and hence, of variations in wool cut per head (Anderson 1979).

In doing research into the effects of rainfall on wool yields, the time at which the forecasts are required and the availability of appropriate rainfall data at that time need to be taken into account. ABARE makes quarterly forecasts of wool production which coincide with meetings of the National Wool Production Forecasting Committee (of which ABARE is a part). The May forecasts are for the forthcoming July–June production year and are therefore likely to have the greatest uncertainty attached to them. The September forecasts occur at the commencement of the main pasture growth period (spring and early summer) for most sheep producing areas, and can be made on the basis of largely known winter rainfall and its possible effect on pasture availability.

The ABARE wool clip forecasting model (Shaw and Findlay 1990) generates forecasts of pasture growth indexes which are then combined with estimates of sheep and lamb numbers and other demographic characteristics to derive forecasts of wool production per head. Pasture growth is modeled as a function of monthly indexes of solar radiation, temperature and rainfall, as well as of the response of plant growth to each of these factors. The ABARE pasture growth model generates values for pasture indexes for the major sheep producing regions for 18 months, ending in the December of the forecast year. An 18 month period is used to reflect the combined effects of pasture growth in one season influencing wool cut per head the following year, and of shearing taking place over different times of the year in different geographic regions.

In recent times, the model has been modified to replace forecasts using median monthly rainfall sets with a set of expected median monthly rainfall values based on the SOI phase indications developed by Stone and Auliciems (1992). Expected rainfall values are used for the months up to and during spring (September–November). Despite this latter modification, it has been found that there is little difference between median rainfall based and SOI based forecasts of wool clip per head (ABARE 1997). As can be seen in table 2, which shows the results for New South Wales for the period 1982–95, there is no clear pattern as to which measure (median rainfall or SOI) results in consistently better forecasts. Median rainfall based forecasts are more accurate in seven years, while forecasts based on SOI phases are more accurate in six other years.

Table 2: **Base of the most accurate sheep yield forecast in New South Wales** a

		Forecasts made in:	
		May	**August**
1982	(5).	SOI	SOI
1983	(1)	median	median
1984	(4)	SOI	SOI
1985	(4)	SOI	SOI
1986	(5)	median	median
1987	(1)	median	median
1988	(5)	median	SOI
1989	(4)	SOI	SOI
1990	(4)	median	median
1991	(1)	median	median
1992	(1)	median	median
1993	(3)	SOI	SOI
1994	(3)	median	median
1995	(3)	SOI	SOI

a One year ahead.
Note: Figures in parentheses next to forecast years indicate phases.

Although ABARE has not so far been successful in improving its wool cut per head forecasts by incorporating SOI data into the forecasting model, other researchers have recently had success in modeling the relationship between SOI data and pasture production for relatively small geographic areas. The Queensland Departments of Primary Industries and Natural Resources in cooperation with the Commonwealth Scientific Industrial Research Organisation (CSIRO) have found a strong relationship between SOI phase and pasture growth in Queensland. This research has used detailed soil and vegetation information to better predict pasture growth on very small areas. Because this approach to forecasting is very labor intensive, it is currently best suited to farm level decision making. However, an objective of the research is to incorporate the records into a database, with a view to developing a more macro level tool for analysing state or national production variations.

Future research directions

Australian research into incorporating ENSO information into agricultural production forecasting is proceeding in three main areas. The basic objectives in these areas of research are, respectively, to improve the reliability and timeliness of climatic forecasts; to develop a means of incorporating the results of global circulation models into agricultural models; and to improve the agronomic aspects of the various models.

With respect to the first area of research, efforts to improve the reliability and timeliness of climate forecasts is a slow process, with most agricultural production models requiring several years of testing and validation before being suitable for use in generating public forecasts. In the case of the third area of research, most efforts to improve agronomic aspects of production models are currently focused on farm level decision models. At the same time though, the collation of small scale information from this research into a database for use in more aggregated models has longer term potential to contribute significantly to improved production forecasts.

As indicated earlier in this paper, one area requiring further research is to better account for the effects of the 'timing' of rainfall events in existing models. Three month climate forecasts currently only give indications of the expected average rainfall over the forecast period. This means that, even if these forecasts accurately predict the average rainfall for the season, they cannot predict the pattern of such rainfall with sufficient accuracy to know whether it will fall at critical times for crop and pasture development.

Independent research in all the above areas can be expected to complement ABARE's own efforts in incorporating weather variables into its production forecasts. Of course, research into climate and the effects on agricultural production is relatively resource intensive, particularly in terms of human inputs. The investment of resources into the area will therefore be dictated to a large extent by competing priorities for research funding. Although public funds for most types of research remain tight, there are signs emerging of greater private sector interest in supporting such research — often in collaboration with public sector agencies. For its part, ABARE will continue to weigh the costs and benefits of such research to its overall program of activities, and will take these into account when allocating resources between projects.

Given the close collaborative arrangements that have been developed at various levels in Australia, the least cost approach to further model development will be to continue with a cooperative, cross disciplinary approach. The promotion of greater linkages across disciplines will be a critical factor in the understanding of the complexities of the economic, biological and ecological relationships existing in the climate/production interface.

Conclusions

A high level of interest in Australia in integrating climate forecasts into agricultural production forecasting models is a reflection of the considerable economic impacts of rainfall variability on the rural sector and on the nation as a whole. Large year to year fluctuations in rainfall have significant implications for farm and regional incomes, for infrastructure development and management, and for commodity trade performance — especially for grains.

The potential payoff from better incorporation of climate forecasts into agricultural production models is likely to be high in terms of both farm and national economic management. The substantial ongoing public investment in climate/production research in Australia is in recognition of this potential.

However, there is a long way to go — both successes and failures have occurred. Nevertheless, significant advances have been made — especially over the past decade or so. As the links between rainfall and agricultural production in Australia become better understood, it seems likely that analysts will be in an increasingly better position to provide improved advice to governments, agribusiness and farmers.

A major challenge for the economics profession, is to successfully incorporate advances in the understanding of weather patterns and their effects on agricultural production into market forecasting models.

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