Seasonal rainfall forecasts as an adaptation strategy for climate change

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Abstract

Seasonal forecasts are critical for dealing with climate variability. As the climate and the variability will change with future climate change, maximising returns from good seasons and minimising losses from poor seasons will become even more important. This study is the first agricultural application of Australia’s seasonal climate forecast model POAMA (Predictive Ocean Atmosphere Model for Australia). POAMA has demonstrable skill at predicting growing season rainfall in the southern wheat–belt of Western Australia. At the study site of Nyabing, POAMA correctly forecast the above or below median seasonal rainfall for 70% of the years between 1980 and 2006. POAMA rainfall forecasts were used to determine optimum nitrogen fertiliser rates based on a realistic conservative strategy that required a reasonable expected return on every dollar invested. Using the POAMA forecast resulted in a higher return of about A$60/ha/year compared to a constant fertiliser application. Improving seasonal and in-season forecasts is important now, but will become even more critical in adapting to future climate change.

Key Words

Agricultural management, global circulation model, POAMA

Introduction

Wheat grain yields in rain-fed agriculture are strongly related to rainfall in Australia. A forecast of a wet or dry season type could potentially be used to adjust management of crops to save input costs in low-yielding seasons and to increase inputs to utilise a higher yield potential in wet seasons. Hammer et al. (1996) have shown that profits could be increased by up to 20% when adjusting crop management based on the Southern Oscillation Index (SOI) phases in the Queensland wheat-belt. However, studies of the SOI phase system in other regions (Ash et al. 2007) have not shown any significant benefits to crop management. For example, applications of the SOI phase system in south-eastern Australia have been estimated to yield an extra A$2-3/ha (Wang et al. 2009; McIntosh et al. 2007). In contrast, the potential of a skilful forecast could be A$12-65/ha (Wang et al. 2009; McIntosh et al. 2007; Moeller et al. 2008). However, most of these studies assumed the relatively risky strategy of adding fertiliser until profits were maximised. This can mean adding $1 of nitrogen to obtain a net benefit of 1 cent. Such a strategy is unrealistic, and might have understated the benefits of the forecasting systems for crop management by overestimating the benchmark no-forecast value. In practice, farmers adopt a conservative approach to inputs due to the inherent high risk and uncertainties in rain-fed agriculture as a consequence of rainfall variability, heat and frost damage potential, pest and disease pressure and wheat price variability.

While statistical methods such as the SOI phase system rely on historical analogue years to define a future season, recent climate trends and climate change might make these systems less reliable in the future. To overcome this, global circulation models (GCMs), which incorporate climate change trends, have recently been employed for crop yield forecasts (Baigorria et al. 2010). The Bureau of Meteorology in Australia is currently developing a seasonal climate forecasting system based on a global coupled ocean-atmosphere GCM (Zhao and Hendon 2009, and references therein). This Predictive Ocean-Atmosphere Model for Australia (POAMA) has not been tested for applications in agriculture yet.

The aim of this prototype study is to explore how best to use POAMA's skill in forecasting rainfall to aid decision making for wheat crop management in the Western Australian wheat-belt. In particular, nitrogen fertiliser application is altered based on whether POAMA predicts above or below median rainfall. The fertiliser rate in each category is determined from historically similar years, and over a range of realistic management approaches from risky to conservative.

Methods

Seasonal forecast

Australia's seasonal climate forecast system POAMA version 1.5b is run by the Bureau of Meteorology, forecasting up to 9 months ahead. The model is a global coupled ocean-atmosphere circulation model initialised at the start of every run using observations. A hindcast (retrospective forecast) data set is available spanning the years 1980 to 2006, from which the skill and value of this version of the model can be assessed.

The hindcast data set used here comprises ten separate forecasts initialised with instantaneous atmospheric analyses every six hours for two and a half days at the start of May from 1980 to 2006. The model output used here is a simple average of the ten ensemble members for the May forecast for the next six months. It is known that the ensemble mean is generally more accurate than any individual ensemble member (Hagedorn et al. 2005). However, the ensemble spread is yet to be shown to be a good estimate of model uncertainty.

The forecast skill of POAMA at predicting May-Oct rainfall from a May start is assessed using the simple "percent correct" in two categories (Wilks 2006). This measure counts the percentage of years that the forecast correctly predicts above or below median rainfall. The median is calculated separately for the model and observed values so that the influence of model bias is removed. The observed rainfall is originally provided on a 0.05 degree grid (Jones et al. 2009), and is aggregated onto a 2.5 degree spatial grid that closely approximates the POAMA grid. POAMA correctly forecast the above or below median seasonal rainfall for 70% of the years between 1980 and 2006. It can be shown by Monte Carlo methods that there is less than a 4% chance that POAMA obtained this 70% score by chance (Asseng et al. 2010).

Agricultural system

The Agricultural Production Systems SIMulator (APSIM) is a crop simulation model consisting of modules that incorporate aspects of soil, water, nitrogen, crop residues, crop growth and development, and their interactions within a crop/soil system driven by daily weather data (Keating et al. 2003). APSIM for wheat (APSIM-Nwheat version 1.55s) has been extensively tested against a range of field measurements from many different environments (Asseng 2004). APSIM-Nwheat was used to generate multi-factorial N rate simulations for a clay soil at Nyabing in the southwest wheat-belt in Western Australia (Asseng et al. 2010).

Simulations included the crop and grain yield responses to 20kg N/ha fertiliser applications up to 200 kg N/ha. Applications above 80 kg N/ha were split with the second application four weeks after sowing. Applications above 160 kg/N ha were split again with this third application at seven weeks after sowing. For simplicity in this analysis, any N fertiliser application was committed at sowing including when applied in splits after sowing. Simulations were done for the same hindcast period as in POAMA (1980 to 2006).

For all simulations soil N and water content were reset every year in autumn to a dry (no plant-available stored soil water) soil profile and a total of 50 kg mineral N ha^{-1} to exclude 'carry-over' effects from previous seasons. The sowing date depended on the start of the autumn rains, consistent with current farming practice. A local variety was sown when rainfall was at least 10 mm over the previous 10 days and the water content in the topsoil (5-10 cm) was at least 50% of plant available water.

Gross margin (GM) was used as a measure of the efficiency of the N fertiliser treatments. GM in A$/ha was calculated as yield times grain price minus variable costs. The base price for one tonne of wheat grain was A$200/t, to which protein premiums were added, or from which penalties were subtracted, depending on the protein content of the grain following the approach of Moeller et al. (2008). A constant set of basic operating costs of A$150/ha was used which included costs of seed, fertiliser other than N fertiliser, sprays, operating of machinery, contractors, crop insurance and interest. The cost of N fertiliser was fixed at A$1/kg N.

Many similar studies have assumed that N fertiliser is applied until the GM is a maximum. However, in practice, farmers adopt a more conservative strategy. N fertiliser is only applied if it is expected that the additional profit exceeds the N cost. For example, a realistic profit target is A$2 increased GM per each A$1 invested in N fertiliser. This target might increase up to A$3 per A$1 of N in extreme low rainfall regions and with very risk adverse farmers. A profit target of close to zero amounts to profit maximisation, and means taking high risks by seeking any additional return, regardless of how small, for each dollar invested in N fertiliser. Such a strategy is unrealistic. A profit target of A$2 per each A$1 invested in N fertiliser reflects the inherent high risk and uncertainties in rain-fed cropping due to rainfall variability, heat and frost damage potential, pest and disease pressure and wheat price variability.

Gross Margins were calculated using the POAMA forecast of a wet or dry year to dictate the N management. Wet years were defined as years with a forecast seasonal rainfall greater than the forecast median seasonal rainfall. Dry years were defined as years with a forecast seasonal rainfall less than the forecast median seasonal rainfall. The optimum N was determined for wet and dry years separately. GMs using the POAMA forecasts were compared to GMs obtained using a fixed N treatment based on the average optimum N calculated over all years from 1980 to 2006. The optimum N calculation was cross-validated (in the leave one out sense) within each group by determining an N application for each year within the group separately, and leaving that year out of the group. This procedure reduces the chance of artificial skill (see McIntosh et al. 2007 for a more detailed description).

Results

The APSIM multi-factorial database was used to determine optimum N fertiliser application amounts separately for all years 1980-2006, for years observed to have above median rainfall, and for years observed to have below median rainfall. The optimised N application rate for a profit target of A$2 per A$1 N for all years was 0 kg N/ha, for the wet years it was 60 kg N/ha, and for the dry years it was 0 kg N /ha. POAMA seasonal rainfall forecasts (above or below median) were then used to select between the two N rates. The sum of the gross margins from the two categories were than compared with the sum of the gross margins from the benchmark all-year data set, which received the same N fertiliser application (0 kg N/ha) each year, regardless of season type. If the returns from managing the two season types differently yielded a higher return compared to the same management across all seasons, it would indicate a potential additional benefit from using POAMA to adjust N fertiliser application rates.

Figure 1 shows for Nyabing in the southern Western Australian wheat-belt the benefits from using POAMA forecasts for managing N fertiliser applications across a wide range of farmer risk taking behaviour in N fertiliser application decisions. The profit target of close to zero additional returns for each dollar invested in N fertiliser represents an unrealistic maximisation of gross margin, which would be extremely risky for farmers and is therefore not practiced in agriculture. However, such an assumption would suggest no value of the POAMA forecast. This is because adding nitrogen to chase maximum profits results in adding 80 kg N/ha without a forecast, and a forecast cannot improve on this. However, a realistic farming practice is a profit target of A$2 returned for each A$1 invested in fertiliser application, which leads to a benefit of about A$60/ha. Risk-adverse farmers in extreme low rainfall regions may take an even more conservative approach and aim for a profit target of A$3 per A$1 N.

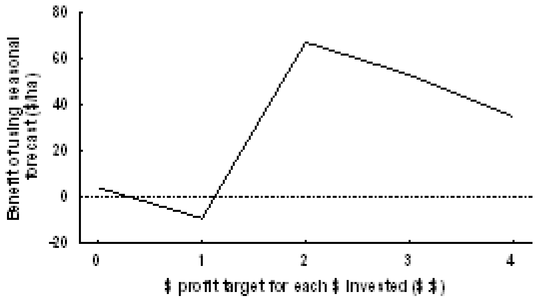

Figure 1. Simulated benefits ($/ha) of using a 2-category POAMA seasonal rainfall (May-October) forecast for N fertiliser management compared with not using a seasonal forecast for clay soil versus a changing profit target (targeted profit for each $ invested in N fertiliser). Simulations are for clay soil at Nyabing in the Western Australian wheat-belt. Wheat price is A$200/t, N cost is A$1/kg N.

The year-to-year benefit of using a POAMA forecast to decide the N application rate is shown in Figure 2 at Nyabing using a A$2 profit target for each A$1 invested in N. The gross margins obtained each year are compared to those obtained using a fixed N strategy based on the same profit target over all years. Figure 2 indicates that the increased returns from applying enough N in good years outweighs any negative returns from a wrong forecast. Note that because the “all-years” and “below median” fertiliser rates are both 0 kg N/ha, there is no penalty when POAMA wrongly predicts a below median year.

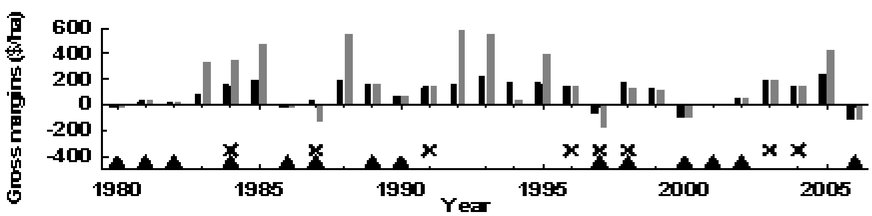

Figure 2. Simulated gross margins using a 2-category forecast of May-Oct rainfall for N fertiliser management (grey bars) compared with not using a seasonal forecast (black bars). Years with a wrong rainfall forecast are indicated with a cross and years with a below median rainfall forecast are indicated with a triangle. Wheat price at A$200/t, N fertiliser cost at A$1/kg N and a profit target of A$2 per each A$1 invested in N fertiliser.

Conclusion

Grain yields and N fertiliser requirements can vary widely between seasons in rain-fed agriculture. Using a seasonal rainfall forecast can assist in adjusting N fertiliser applications to variations in potential yield according to rainfall season types. The POAMA seasonal rainfall forecast has significant skill in forecasting rainfall season types in some regions of the Western Australian wheat-belt which can translate to A$60/ha of additional returns when used in N management decisions in wheat cropping. It is important to model realistic risk behaviour in relation to farm management when determining the benefits of using a forecast system for management decisions in agriculture.

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