Effects of a changing climate on wheat cropping systems in northern New South Wales

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Abstract

Cropping systems are sensitive to climate variability and climate change. This study identifies long-term trends (non-stationarity) in minimum winter temperatures and rainfall at Gunnedah (NSW, Australia) and assesses their impacts on monoculture wheat systems in the same region using the Agricultural Production System Simulator (APSIM). To identify these trends in climatic and agricultural time series it was necessary to account for variation due to auto-correlation and ENSO before a climate change signal emerged. Significant increases were found in minimum winter temperatures and accumulated seasonal rainfall. Resultant wheat yield increases were then found, once ENSO variability was identified, however such increases would likely be offset in “real-world” systems by increases in lost natural resources, such as soil and water.

Media summary

There is evidence of changes in long term temperature and rainfall records at Gunnedah in northern New South Wales. Simulations of wheat yields with the APSIM model showed that these changes caused increased yields.

Key words

APSIM, climate change, multivariate regression analysis, wheat, ENSO.

Introduction

There is strong evidence for the existence of climate change (Suppiah and Hennessy, 1998; Collins et al., 2000; IPCC, 2001) with subsequent impacts on agricultural systems (Howden et al., 2003). Via the Agricultural Production System Simulator (APSIM) (Keating et al., 2003) we quantify these climate change impacts, both in grain production and environmental terms, for the Gunnedah region of northern New South Wales. This case study is part of a larger initiative funded by Land and Water Australia. Identification of the possible drivers of the evident non-stationarity, such as anthropogenic causes or low-frequency climate variability, is beyond the scope of this paper.

Trends in climate factors can be masked by background climate variability such as intra-annual, ENSO and inter-decadal variability. Hence, we used a multivariate approach to identify long-term trends by fitting statistical regression models. This accounted for variability due to other mechanisms (e.g. seasonality, ENSO, intra/inter-decadal variability) before a long-term trend was fitted. Depending on the climatic variable being modelled, either a classical linear regression model, or a generalised linear model was used.

This analysis was applied to APSIM generated data such as wheat yields and cumulative annual runoff, drainage and erosion. For the simulations we assumed constant management with respect to nitrogen application, cultivar selection, and planting date, thus avoiding any technology trends and guaranteeing that any remaining trends in the simulations were entirely due to responses to climate inputs. Further, problems caused by continuous monoculture cropping, such as weeds, disease and soil degradation were not included in the APSIM model.

In this paper we quantified the trends in annual winter minimum temperatures and annual rainfall (accumulated from the start of the fallow until harvest) over the last century, and we investigated the effects of these trends on yields, water and soil loss in a monoculture wheat system in northern inland New South Wales.

Methods

Climate data

To conduct trend analyses on raw climate data, it is essential to have a long record of high-quality historical data. Hence, a composite series of data from the CLIMARC Project (Clarkson, 2002) and the Bureau of Meteorology was used for trend analysis on temperatures and precipitation. The APSIM crop models require a continuous daily time series of at least maximum and minimum temperatures and rainfall. As the composite series for Gunnedah is discontinuous (eg. prior to 1913, no weekend observations were available), it was necessary to patch (Jeffrey et al., 2001) and hence infill missing data. The resulting time series were then checked for inconsistencies using TAMET (Wall 1977) before they were used in APSIM.

Wheat modelling

To quantify the impact of climate change on wheat production at Gunnedah, wheat sowing was simulated on the 1st June, a date corresponding to a conservative frost risk and using parameters representative for an early maturing wheat variety. A soil with a plant available water content of 120 mm was used in the simulation. To avoid nitrogen limitations, 150 kg/ha of nitrogen was applied at sowing. Natural resource indicators such as runoff, drainage, erosion and rainfall were accumulated from harvest to harvest, typically late October or early November. Soil water was set to 10% of capacity at each harvest to ensure that no autocorrelation (dependency between successive terms in the time series) occurred due to carryover of unused soil water. Hence, any remaining autocorrelations are a consequence of the historical climate data.

To model the effects of frost on wheat yields it was assumed that the frost sensitive period for wheat is from anthesis to the end of grain filling (Woodruff and Tonks, 1983). Currently APSIM-Wheat does not model frost affected yields. We modelled a frost affected crop as one experiencing a screen minimum temperature of 2?C or less on any day between anthesis and the end of grain filling, inclusive. This represents a conservative approach which takes into account local topography (i.e. ‘frost pockets’) that can increase frost risk (Hammer and Rosenthal 1978). Whenever such an event occurred, the corresponding simulated wheat yields for that season were assumed to be zero.

Analysis

To extract long-term trends from each time series we used statistical models to account for variability due to other factors, which may be cyclical but are essentially stationary. The order in which terms appear in the model should approximate the order of importance in influencing the response. This is because the significance that each term has depends on preceding terms that have been fitted, and hence the variability accounted for by these preceding terms. For this reason the response (independent) variables, such as minimum winter temperatures, rainfall, wheat yields, erosion, runoff and drainage were originally modelled by terms in order from most perceived influence on the response variable to least. The regressor (dependent) terms and the order in which they originally appear in the model are: the previous 1- to 5-year values of the response variable (to account for autocorrelation, referred to as lag1 to lag5), the ENSO classification for each year (Potgieter et al. 2004), a 9- to 13-year decadal index (Meinke et al., 2004) and the year, a term which represents the yearly changes in the response variable (i.e. a linear trend). After initially fitting all the regressors, insignificant ones were removed (using an analysis of deviance) and the model re-fitted. This process was performed iteratively until only significant covariates remained. Each remaining regressor was then checked for interaction with the long-term trend.

Due to the discontinuous nature (i.e. ‘zero’ versus ‘non-zero’ values) of time series such as wheat yields, drainage, runoff and erosion, a Tweedie Generalised Linear Model (Lennox et al. 2004) that can model both discrete and continuous distributions was used. Once each model was created, its suitability was checked using normal probability plots as outlined in Lennox (2003).

Results and discussion

For all variables (climatic and agricultural) ENSO had a significant effect, however each ENSO classification was not necessarily significantly different from the other. For example, for drainage, runoff and erosion there was no significant difference between El Ni?o and “other” years (see Figure 1). Once ENSO variability was accounted for, the slope of a linear long-term trend was significantly different from zero. Hence a positive long-term trend exists at Gunnedah since 1901 for all variables being modelled.

Wheat yields were reduced to zero 25 times from 1901 to 2002 due to frost, and twice (1946 and 1965) due to water stress. A time series of wheat yield (Figure 2) shows approximately 71% of these zero yields (due to frost) occurred before 1950, and Figure 1a. shows an associated increase in winter minimum temperatures of greater than 1?C over the last century. When combined with a 200 mm increase in annual rainfall, the effects on average yields can be seen in Figure 1c, which describes a 2000 kg/ha increase in potential yields for La Ni?a and “other” years and a 1000 kg/ha increase in yields for El Ni?o years since 1901.

This positive result however is offset by significant increases in drainage, runoff and erosion due to the increased amount of water entering the agricultural system. The impact of soil degradation on wheat yield was not modelled in this study because we attempted to model climatic variability under constant management practices.

For all variables tested no interaction terms were found to be significant. For this reason the effect that ENSO has on each response is independent of the year. For example, climate change does influence the effect that ENSO has on wheat yields at Gunnedah.

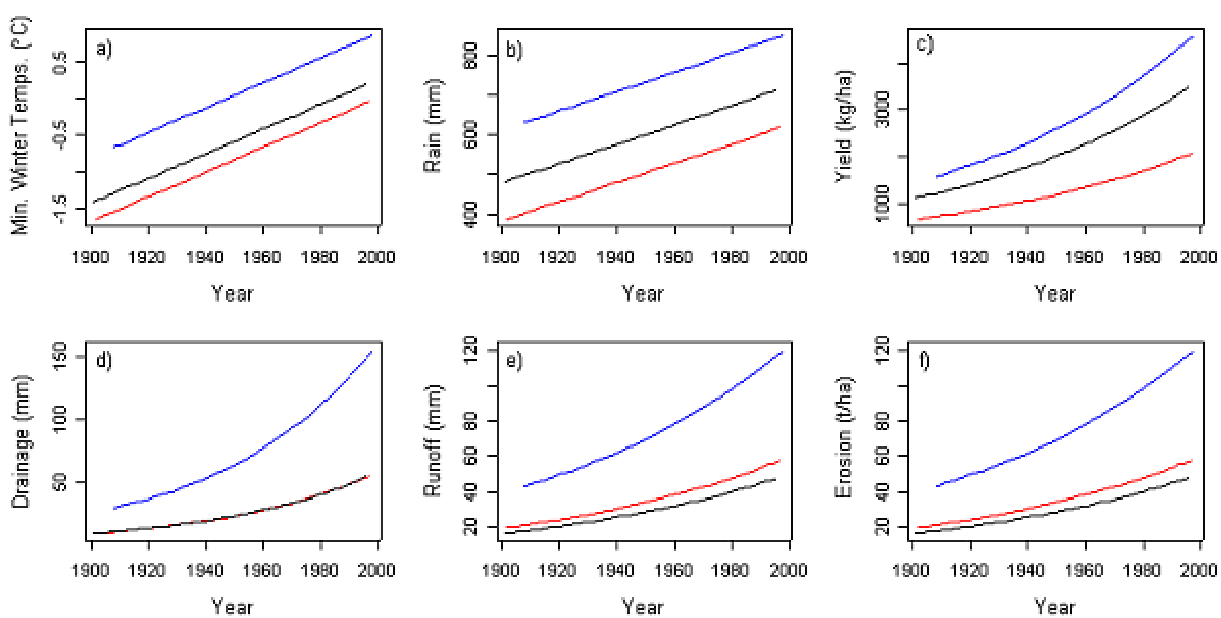

Fig. 1. Long-term trends for each climatic and agricultural element for each yearly ENSO classification[La Ni?a (blue), El Ni?o (red) and “other” years (black)] after variability due to other regressors was removed.

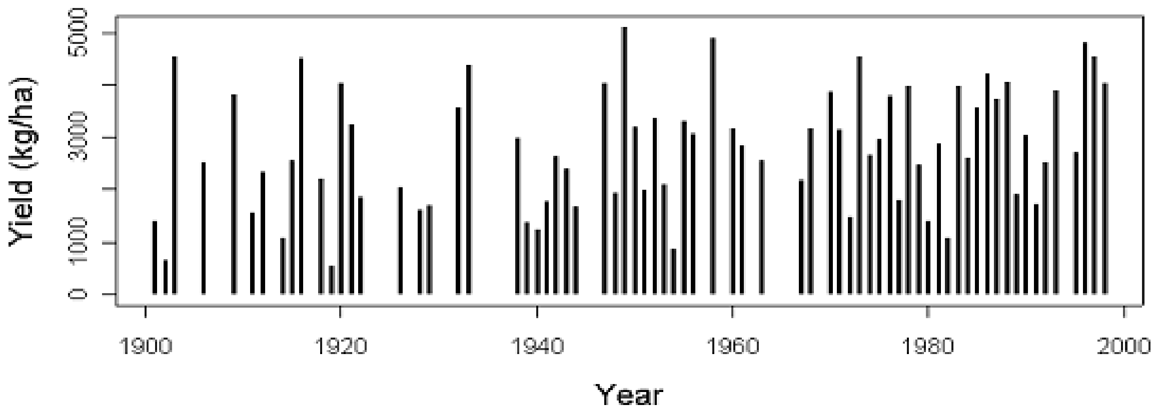

Fig. 2. A time series of simulated wheat yields for the Gunnedah region.

Conclusion

This paper highlights the significant trends in winter minimum temperatures and rainfall that have occurred over the last 100 years, and using APSIM, shows the possible consequences for a wheat monoculture at Gunnedah. The challenge for regional and farm-scale decision makers is to develop management strategies that, while benefiting from increasing production levels from the changed climate, can reduce the environmental impacts.

While the impacts described here represent historical trends, projection studies will rely on further work linking farm-scale crop growth models such as APSIM to global circulation models.

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