Importance of extreme climate events on annual pasture production in south eastern Australia

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Abstract

Most studies of climate change impacts on pasture systems have focussed on pasture growth responses to average changes in temperature and rainfall but, the impacts of increased frequency and severity of extreme climate events (droughts, floods and heatwaves), may be more harmful than changes in average climate. To test the impact of extreme climate events on pasture yields, prediction equations using mean annual and seasonal rainfall and temperatures were compared to ones that also incorporated extreme events (including 'wet' and 'dry' periods based on the standardized precipitation index, frost days, frost duration, hot days and hot day duration). Pasture growth was simulated with DairyMod using daily climate data (including historical carbon dioxide (CO_2) concentrations) from Ellinbank and Dookie sites in south-eastern Australia for the period 1960-2015. The regression equation with mean climate statistics at Ellinbank and Dookie explained 52.3% and 71.2% (R^2) of the annual yield variation respectively. The regression equations that also incorporated extreme events explained 62% and 89% of the yield variation at Ellinbank and Dookie respectively with annual rainfall, winter temperature and CO_2 being the favourable climate factors. However, extremes of rainfall distribution (wet and dry months) and the hot day (>30°C) duration affected pasture growth negatively. Analysis of climate records at Ellinbank showed that spring maximum temperatures and the hot day duration had increased in recent decades demonstrating the importance of extreme climate events in the variability of pasture-based systems and highlighting that they must be considered in future pasture growth studies and climate change analysis.

Key Words

Average climate, perennial ryegrass, phalaris, white clover, subterranean clover.

Introduction

Even though a great majority of studies on climate change and their impacts on agricultural systems have focused on the mean climate change, extreme climate events can cause more damage and long lasting impacts (Thornton et al. 2014). Global climate models have projected that south eastern Australia will be warmer and drier in the future, accompanied by more frequent and severe extreme climate episodes (CSIRO and BOM 2015). Pasture based agricultural systems are vulnerable to these changing climate and extremes particularly because pastures grown in the region (such as perennial ryegrass and phalaris) are sensitive to temperatures above 30°C and severe water stress (Jiang 2001). These climate factors have been identified as the two key climate variables that cause seasonal and inter-annual variation in pasture production and persistence (Nie et al. 2004). Recent literature has shown that the increased frequency and severity of extreme heat waves, longer droughts and extreme precipitation events will cause larger reductions in pasture yields compared to changes in the average climate alone (Harrison et al. 2016). However, understanding which extreme climate events have a significant impact on pasture production, and how this varies across sites, would help to inform climate change impact and adaptation research. In this study we investigate which extremes are important determinants of pasture yield at two sites in south eastern Australia.

Methods

Pasture growth simulation

The effects of annual and seasonal climate averages (hereafter termed 'general' climate) and extreme indices on annual pasture yields were examined at two south eastern Australian sites in medium (Dookie) and high rainfall (Ellinbank) zones. Net herbage accumulation rates (t DM/ha) of the two sites were modelled from 1960-2015 using daily weather data and local soil properties using the DairyMod biophysical model (Johnson et al. 2008). Annual atmospheric CO_2 concentrations, measured at Cape Grim, Tasmania were incorporated into the climate data. Pasture species were perennial ryegrass (*Lolium perenne*) and white clover (*Trifolium repens*) at Ellinbank whereas phalaris (*Phalaris aquatica*) and subterranean clover (*Trifolium subterraneum*) pastures were modelled at Dookie. Further site details are shown in Table 1. Pasture was simulated as a cut trial with standing biomass cut to 1.4 t DM/ha at the end of each month, using nutrient non-limiting and non-irrigated conditions. Perennial ryegrass, white clover and subterranean clover pastures were parameterised for onset of heat stress when the daily maximum air temperature exceed 30°C and to completely cease pasture growth above 35°C. Recovery function of pasture species following the heat stress is represented in the model as the 'critical temperature sum' to resume the full photosynthetic capacity. When the summation of daily values of 25°C minus mean daily temperatures reaches the 'critical temperature sum', plants have recovered from the heat stress. For example if the 'critical temperature sum' for recovery in perennial ryegrass is 50 and the mean daily temperature on the following day is 20°C then there are 5 heat units accumulated during that day, and the plants will fully recover from the heat stress after 10 days of 20°C. In phalaris, initial stress and maximum stress were exerted at 31°C and at 36°C respectively as phalaris is more heat tolerant than perennial ryegrass. The recovery function of phalaris was set to 200 because of the summer dormant nature of the phalaris plant.

Table 1. Site description, including location, soil type, climate zone, average annual rainfall (1960-2015) and maximum and minimum temperatures.

Site	Lat., Long.	Soil type	Climate	Rainfall (mm)	T max (°C)	T min (°C)
Dookie	-36.37, 145.70	Vertic Calic Red Chromosol	Medium rainfall temperate	559	20.4	8.0
Ellinbank	-38.25, 145.93	Red Mesotrophic Haplic Ferrosol	High rainfall temperate	1046	18.7	8.8

General climate variables and extreme climate indices

To explore annual yield variability in response to climate variability and extreme events, two sets of climate parameters were developed. General climate statistics such as annual rainfall (mm), annual and seasonal maximum and minimum temperatures (°C) and average annual CO_2 concentrations (ppm) were used to understand the relationship of general climate variables with annual yields. Extreme climate indices were developed using precipitation data and minimum and maximum daily temperature data to explore yield variability associated with climate extremes. Wet and dry months were categorized according to three month SPI drought intensity classes (McKee et al. 1993). Moderately, severely and extremely dry months were categorized using the SPI values between -1 and -1.49, -1.5 and -1.99 and -2 or below respectively. Wet months are defined in analogous way to dry months using the positive values of SPIs. Number of hot days were calculated as days with maximum daily temperature >30°C during a calendar year. Hot day duration was calculated starting from the beginning of the year (January) until the last hot day around autumn and then added the hot period starting from second half of the year (around spring) to December in the same year. Cold extremes were computed as number of frost days ($T_{min} \leq 2$°C) in a year during winter and spring time and frost period length was the duration in between first and last frost day within those months. These two periods were used because the frost is more common during this time of the year.

Statistical analysis

Annual pasture yields were related to climate predictors using a step-wise multiple linear regression procedure with backward elimination of terms, using Minitab 17 statistical software. This was carried out in a two-step procedure, first annual yields were regressed with general climate statistics to explore the yield determining climate variables. Secondly, extreme climate indices together with general climate variables were regressed with annual pasture yields to identify the extreme climate indices that accounted for the majority of yield prediction at the two sites.

Results and Discussion

Prediction equation with general climate statistics explained 52% of the yield variability at Ellinbank with average annual rainfall, average maximum spring time temperature and CO_2 concentration being significant (P<0.05). Pasture growth response at Dookie was highly related to annual rainfall explaining 71% of the total yield variation. Except for maximum spring time temperatures at Ellinbank, average climate statistics showed positive relationship with pasture yields at both sites (Table 2, Figure 1(left)).

Regression equations that also incorporated extreme climate indices explained more of the yield variability; 62% at Ellinbank and 89% at Dookie (Table 2, Figure 1(right)). The significant predictor variables among extreme climate indices at medium rainfall site (Dookie) were severely and extremely dry months and extremely wet months, showing negative relationships with yield. Apart from extreme climate indices, average annual maximum temperature also showed negative impacts on pasture growth at Dookie. However, increasing winter temperatures showed a positive relationship with annual pasture yield because of winter season pasture growth is limited by the low temperature as the winter temperatures are at sub-optimum levels to the plant growth (McKenzie et al. 1999). Heat stress reduced the pasture growth at Ellinbank where perennial ryegrass pasture yields showed negative relationship with increasing heat stress duration. Increasing hot days during growing period due to heat waves can also interact with moisture deficits that can increase the negative effects (Jiang 2001).

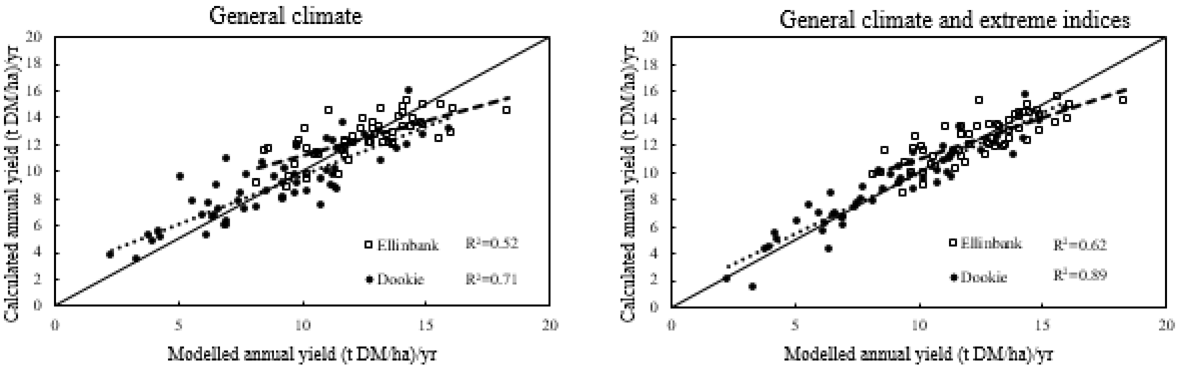

Figure 1. Comparison between modelled and calculated annual yields with 1:1 line of (left) General climate and (right) General climate and extreme indices at Ellinbank (□) and Dookie (●).

In this analysis, amount of rainfall and rainfall distribution appeared as significant yield determining factors (*P*<0.05) in both medium and high rainfall sites. Chapman et al. (2009) reported rainfall as the strongest driver of climate that determine monthly pasture growth variability in south eastern Australia and New Zealand. Further, Radcliffe and Baars (1990) showed that 60% of the pasture yield variability in New Zealand sites were due to spring and summer rainfall. At the high rainfall site (Ellinbank), higher rainfall events such as moderately and extremely wet months negatively correlated with annual yields. This may be caused by water logging effect. Water logging creates anaerobic conditions in the root zone leading to poor gas exchange (Moore 2001). Trend analysis of significant temperature variables at Ellinbank shows that spring time maximum temperature and hot period length have been increasing particularly from 1990 to 2015 (Figure 2).

Table 2. Comparison of significant variables of the regression equations; significant regression coefficients of the general climate and general and extreme indices are provided. NA-Not applicable, Ns-Not significant.

Climate variable matrix	Climate variables	Dookie		Ellinbank	
		General	General and extreme	General	General and extreme
General climate	Annual average rainfall	0.02	0.01	0.01	0.01
	Annual average Tmax	Ns	-1.42	Ns	Ns
	Annual average Tmin	Ns	Ns	Ns	Ns
	Average Tmax-summer	Ns	Ns	Ns	Ns
	Average Tmax -autumn	Ns	Ns	Ns	Ns
	Average Tmax -winter	Ns	1.24	Ns	Ns
	Average Tmax -spring	Ns	Ns	-0.64	Ns
	Average Tmin-summer	Ns	Ns	Ns	Ns
	Average Tmin -autumn	Ns	0.52	Ns	Ns
	Average Tmin -winter	Ns	-0.85	Ns	Ns
	Average Tmin -spring	Ns	0.84	Ns	Ns
	CO2	Ns	0.02	0.04	0.04
Extreme climate indices	Moderately dry months/yr	NA	Ns	NA	Ns
	Severely dry months/yr	NA	-1.35	NA	Ns
	Etremely dry months/yr	NA	-0.61	NA	Ns
	Moderately wet months/yr	NA	Ns	NA	-0.44
	Severely wet months/yr	NA	Ns	NA	Ns
	Extremely wet months/yr	NA	-1.16	NA	-0.72
	Winter-spring frost days	NA	Ns	NA	Ns
	Frost period length	NA	Ns	NA	Ns
	Number of hot days/yr	NA	Ns	NA	Ns
	Hot day duration	NA	Ns	NA	-0.02
	R^2	71%	89%	52%	62%

The results show that we are likely to get more climate extremes in the future and their impacts on annual pasture yields will be greater. Therefore it is important to consider these trends in future climate change impact and adaptation research.

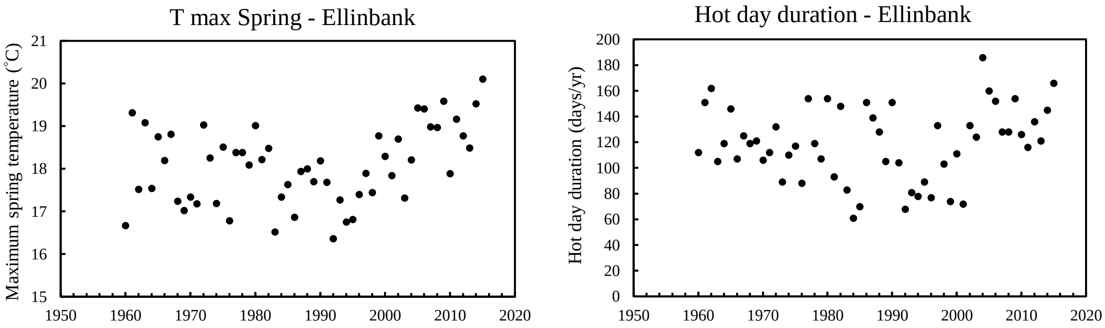

Figure 2. Time trends of (left) maximum average spring temperatures and (right) hot period length at Ellinbank.

Conclusion

This analysis has shown that using extreme climate indices together with general climate statistics is more effective at explaining yield variability than considering climate averages alone. Time trends of temperature extremes show that their frequency has increased. These results highlight that extreme events must be considered in future climate change studies.

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