Past and future competitiveness of wheat and beef cattle production in Emerald, NE Queensland.

Howden, S.M[1]., McKeon, G.M[2]., Reyenga, P.J[3]., Entel, M[4]. Meinke, H[5]. and Flood, N[2].

1 CSIRO Wildlife and Ecology, GP Box 284, Canberra, ACT, Australia, 2601
2 Climate Impacts and Natural Resources, QDNR, 80 Meiers Rd, Indooroopilly, Qld, Australia, 4068
3 Bureau of Rural Sciences, P.O. Box E11, Kingston, ACT, 2604
4 Meteorology CRC, Monash University, Wellington Road, Clayton, Vic 3168
5 Agricultural Production Systems Research Unit, DPI/DNR/CSIRO, P.O. Box 102, Toowoomba, Qld, 4350

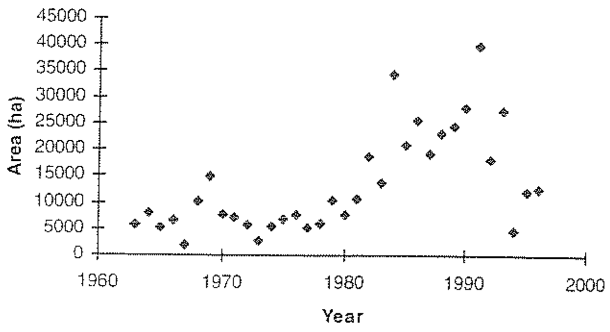
Abstract Emerald, north-east Queensland is at the northern margin of the wheat cropping region of Australia. The Emerald region was previously used predominantly for grazing beef cattle, however, cropping has developed in importance over the past 30 years. We use historical climate records (1890-present) to simulate and compare wheat yields, grass production and liveweight gain (LWG) over time. The cropping expansion from the 1970s to the early 1990s has occurred in a unique period in the 108-year record with the highest average wheat yields, lowest wheat yield variability and the greatest relative productivity of wheat production against grass production. If this window of opportunity is a result of long-term climate variability, then cropping is likely to decline in the region as conditions return to those experienced earlier in the record. If this increase is related to climate change, then cropping is likely to persist in the region with productivity maintained at current levels particularly through the yield-enhancing effects of increased atmospheric CO_2 concentrations. However, this persistence will be influenced by the frequencies of El Niño conditions which may increase with global warming. The high relative productivities experienced over the past few decades have probably biased producers expectations, and applications for drought support need to take into account the longer-term perspective provided by this analysis. Nevertheless, the last six years have the lowest simulated mean LWG production on the record. The identification of poor production periods depended on the production element being addressed and the timescale involved.

1. INTRODUCTION

Managing climate variability is a key requirement for Australian livestock and cropping industries (eg Meinke and Hammer 1995). Farm management and government policies require analyses based on probabilistic information (eg Stafford Smith and McKeon 1999). These analyses typically use climate information from a 40 to 100 year record. However, recent evaluations suggest that there is long-term variability in our climate record (eg Isdale *et al.* 1986; Power *et al.* 1999) and this along with the possible emergence of trends related to climate change and increased atmospheric concentrations of carbon dioxide (CO_2) raise issues about the applicability of such evaluations (McKeon *et al.* 1998). Furthermore, such evaluations typically focus on one industry in isolation whereas shifts between industries can be a rational response to climate variations. For example, the peanut industry further south in Queensland expanded considerably in response to favourable climatic conditions followed by retraction when these conditions reverted (Meinke and Hammer 1995). There is thus a general expectation that agricultural industries at the climatic margin will be most affected by changes in climate means and variability and are thus appropriate locations for study of long-term industry viability.

Emerald, north-east Queensland (23° 34' S, 148° 11' E) is at the northern margin of the wheat cropping region of Australia. The Emerald region was previously used predominantly for grazing beef cattle, however, cropping has developed in importance over the past 30 years (Fig. 1). The trends in climate documented by McKeon *et al.* (1998) suggest that it is possible that the relative suitability of cropping versus grazing in Emerald is an artifact of recent climate. In addition, increasing concentrations of CO_2 in the atmosphere may have had an impact on yields. Expectations of further changes in climate and CO_2 concentration suggest that relative productivity of the grazing and cropping landuses will change in the future (Howden *et al.* 1999b). The implications for industry and policy will be different if change in cropping area is due to long-term variability or to climate change. We use simulation models of grazing systems (GRASP) and wheat cropping systems (I_WHEAT) to assess the relative biological productivities of these two landuses over the last 108 years using a daily climate record and recorded CO_2 concentrations. We compare these results with a set of global

Figure 1: Area of wheat cropping in the Emerald Statistical Local Area



change scenarios consisting of combinations of CO_2 and climate change.

2. METHODS

GRASP description

GRASP (McKeon *et al.* 1990) is a model simulating the above-ground yield of a sward dominated by perennial native grasses. A full description of each equation is given in Littleboy and McKeon (1997). Evaluation, calibration and validation are described in Day *et al.* (1997) including for the *Dichanthium* pastures where cropping occurs in Emerald. GRASP was run with a responsive stocking strategy aiming to use 20% of the standing biomass present at the 1st June.

The changes to GRASP to incorporate CO_2 effects are extensions of those described in Howden *et al.* (1999a). Parameterisations of GRASP were largely made through experimentation around 1990 when CO_2 levels were about 355ppm and all parameter changes were scaled against this CO_2 concentration. Parameters relating to transpiration were altered linearly with CO_2 concentration between values of 280ppm (pre-industrial levels) and 700ppm (doubled current levels) using the relationships in Howden *et al.* (1999a). Similarly radiation use efficiency (RUE) was varied linearly to increase by 5% with CO_2 concentration of 710ppm and reduced linearly by 8% at 280ppm.

I_WHEAT description

I_WHEAT is a wheat crop module of the APSIM modelling system which simulates soil moisture, soil carbon:nitrogen dynamics and residue management. A full description of I_WHEAT and model testing is given in Meinke *et al.* (1998). Changes to I_WHEAT to simulate variable CO_2 environments are documented in Reyenga *et al.* (1999a). Management and soil parameterisations are as in Howden *et al.* (1999b). I_WHEAT adequately simulates yield from statistical areas (Howden *et al.* 1999b).

Regressions of dewpoint as a function of maximum and minimum temperature (Eq'n 1) were calculated from the post-1957 Emerald record, and pan evaporation was calculated as a function of maximum and minimum temperature and solar radiation (Eq'n 2) from the 1975-1994 period when Emerald pan values were more likely to be accurate. These relationships were then used to calculate pan evaporation and dewpoint consistently over the whole climate file. GRASP uses dewpoint, assumed to be reached at minimum daily temperature, to calculate vapour pressure deficit. Simulations with measured humidity and pan evaporation against the reconstructed values showed strong correspondence (within 5%) and no difference in average values over 40 years (data not shown).

Dewpoint (°C) = $1.45 - 0.0448T_{max} + 0.884T_{min}$
(r^2=0.727, n=13000) *(Eq'n 1)*

Pan evaporation (mm/day) = $-3.60 + 0.126T_{max} + 0.101T_{min} + 0.219S_{rad}$ (r^2=0.77, n=7304) *(Eq'n 2)*

The long-term CO_2 record was constructed from the ice-core data of Etheridge *et al.* (1998) and more recently from the direct atmospheric measurements at Mauna Loa (Keeling and Whorf 1998). Linear interpolation was used for values for years in which no measurement occurred.

Climate change and CO_2 scenarios

Mid-range scenarios of atmospheric CO_2 concentrations suggest an increase from the current levels of 364ppm to about 700ppm by the year 2100 (Houghton *et al.* 1996). This is expected to result in global warming as well as uncertain changes to rainfall characteristics. Global change scenarios were constructed with 1) 700ppm CO_2 but with historical climate, 2) 700ppm but with temperature increases of 3°C, 3) both CO_2 and temperature increase but with 10% rainfall decrease and 4) both 700ppm CO_2 and temperature increase but with 10% rainfall increase. The climate change scenarios were implemented as in Howden *et al.* (1999a) with pan evaporation recalculated as described previously.

Data analysis

Wheat yields, grass yields and LWG and their coefficients of variation (CV) are presented as running means to allow ready comparison over periods of different lengths. In all cases the mean presented is that of the preceding number of years (eg a running mean of 20 years for 1950 is the mean for the period of 1931 to 1950).

To compare relative biological productivities of the cropping and grazing industries we calculated two annual indices by dividing wheat yield by grass production and wheat yield by LWG/ha.

We also compare El Niño events and values of the Interdecadal Pacific Oscillation (IPO), an index of decadal and multi-decadal climatic variability derived from the principal component score of the third empirical orthogonal function (EOF3) of a near-global sea-surface temperature analysis, (Power *et al.* 1999) with the above results.

3. RESULTS

The 5-year running mean of wheat yield has been above the mean since the 1960s and was the highest on record during the 1980s but declined towards the overall mean over the past few years (Fig. 2). The lowest 5-year running mean yield occurred in 1905 but was similar to several values in the 1930s. The lowest 20-year mean occurred in the late 1930s to 1940s with the greatest value occurring over the last few decades.

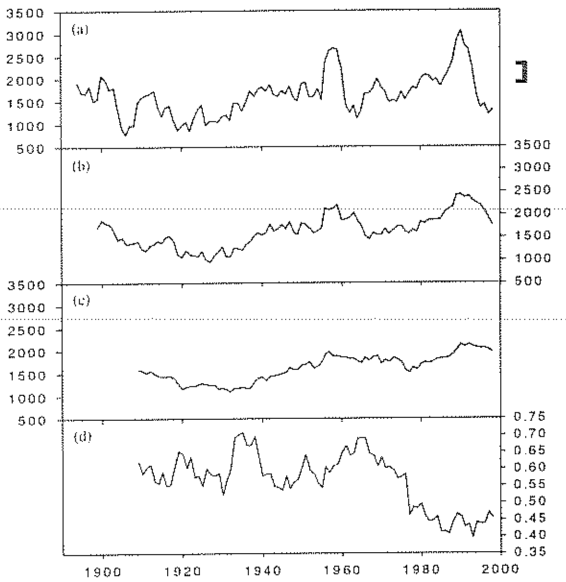


Figure 2: Wheat yield (kg/ha) running means for (a) 5, (b) 10, (c) 20 year periods and (d) 20 year running mean coefficient of variation for Emerald. The bar on the top right indicates the range of mean yields for the year 2100 global change scenarios.

For grass yield, the lowest 10 and 20-year means were found in the 1930s to 1940s, whilst the highest on record were experienced over the last few decades declining to the mean over the past few years (Fig. 3). The lowest 5-year mean value was in 1996 although this was again similar to values in the 1930s to 1940s.

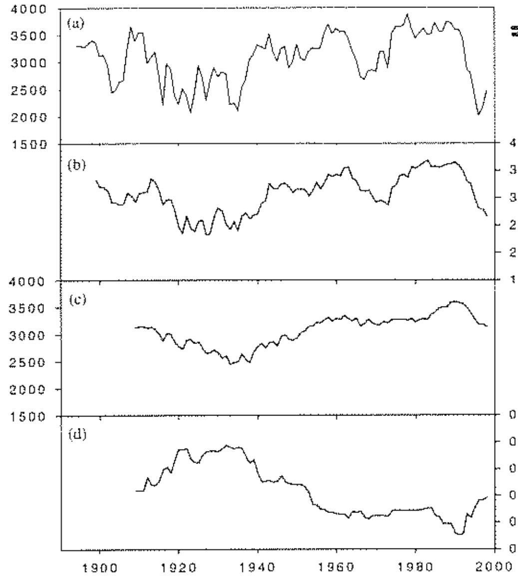


Figure 3: Grass production (kg/ha) running means for (a) 5, (b) 10, (c) 20 year periods and (d) 20 year running mean coefficient of variation for Emerald. The bar on the top right indicates the range of mean production for the year 2100 global change scenarios.

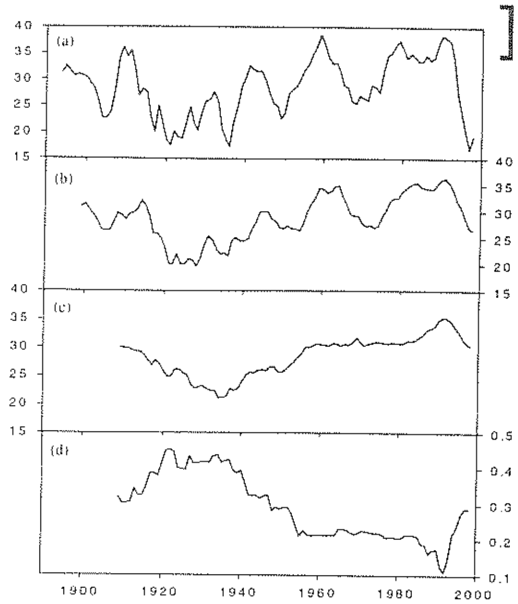
For LWG, the lowest 10 and 20-year running mean values were found in the 1930-40s and highest values over the past decades, although they have been declining over the last several years with the 5-year mean in 1997 being the lowest on record (Fig. 4).

The 20-year running mean of the ratio of grain:grass production has been above the overall mean since the 1970's and over the past few years has been the equal highest on record. The ratio of grain:LWG has been above the overall mean over the past two decades but was below the overall mean from the 1950s to the 70s (Fig. 5).

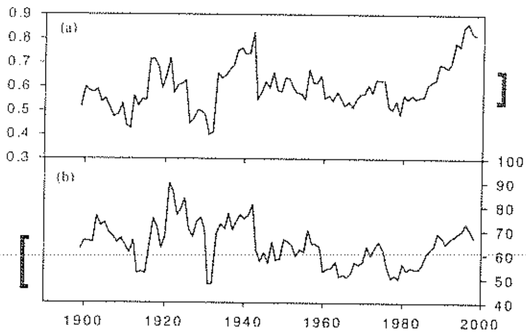
The coefficient of variation (CV; 20 year running mean) varied by a factor of 1.8 over the period for wheat and 3 for grass yields but a factor of 4 for LWG. The CV for wheat declined sharply following 1976 and has remained the lowest on record since then. For grass production and LWG, there was a marked decline in CV from the mid-1950s and has remained low except for LWG which has increased to the mean over the last decade. The periods around the 1940s had high variability for all production systems.

El Niño and La Niña events had a marked effect on wheat and grass production but smaller effects on LWG (Table 1). EOF3 values show peaks around 1900, the 1930-1940 period and 1980 onwards.

Figure 4: LWG (kg/ha/year) running means for (a)



5, (b) 10, (c) 20 year periods and (d) 20 year running mean coefficient of variation for Emerald. The bar indicate the range of mean LWG for the



year 2100 global change scenarios.

Figure 5: Ratio of (a) wheat yield (kg/ha) to grass production (kg/ha) and (b) wheat yields to LWG/ha for Emerald. Bars indicate the range of mean ratio for the global change scenarios.

Increases in CO_2 levels over the past 108 years were simulated to increase wheat production by about 8% and grass production by about 5% with most of this change occurring since the 1960s (data not shown).

Table 1. Effect of average SOI values for June-November on annual wheat yield (kg/ha), grass growth (kg/ha) and LWG (kg/ha) for 1890-1998.

	SOI<-5	-5<SOI<5	SOI>5
Wheat yield	1130	1680	2100
Grass growth	2313	3172	3573
LWG	25.8	29.4	29.5

The CO_2 and climate change scenarios gave a range of wheat yields from +12 to +29%, grass yields of +2 to +17% and LWG of +5 to +57% above the means of those experienced since the 1890s using recorded climate and CO_2 concentrations. These values straddle the 20-year mean for the most recent decades for wheat and grass production but are higher for LWG (Fig. 2,3,4). Doubling of CO_2 concentration without climate changes increased the ratios of wheat:grass production and wheat:LWG by 27 and 17% respectively. Changes in CO_2 in conjunction with climate changes resulted in little change in this ratio against the Baseline for grass production (except for the Wet scenario with +9%) but around 20% decreases for LWG.

4. DISCUSSION

The recent expansion of wheat cropping in the Emerald region appears to have been a response to a changing environment (both climate and CO_2 changes). The period of major expansion from 1980 to the early 1990s had by far the greatest mean wheat yields and the lowest variability of yield in the past 108-years. Furthermore, increased yields associated with progressive reductions in frost frequency over this period may underestimate this simulated change (Stone *et al.* 1996). The relativity of wheat production against grass growth was also the highest on record whilst the ratio of wheat production against LWG was also above average suggesting that the timing of change from grazing to cropping was not just a result of historical development paths or technological change but rather a rational response to a change in the relative productivities and risks of the respective industries. Meinke and Hammer (1995) also have suggested that the peanut industry expansion in south-east Queensland in the 1960s and 1970s was driven by similar climate variations and there are other examples in Australia's history (eg those relating to the Goyder Line in South Australia; Reyenga *et al* 1999b). Increases in CO_2 probably had a small but positive effect (less than 8%) impact on wheat yields.

This suggested response of the cropping industry to growing conditions raises the issue of future stability of the industry in this location. If this favourable 'window' for cropping is a result of long-term variability, then return to more average conditions is inevitable and cropping will decline. If the 'window' is due to climate change, then some continuation of wheat cropping appears likely provided the incidence of El Niño events doesn't increase. Simulations of future potential yields under climate change and CO_2 increase suggest wheat yields that are 12 to 29% above the 108-year average but similar to those experienced in the high-yielding period in the 1980s. In contrast, in most other wheat cropping areas in

Australia, increases over recent yields are likely (Howden *et al.* 1999b) the relative lack of response being due the likelihood of supra-optimal temperature conditions at Emerald. The historical correspondence of periods of low yield with El Niño events is cause for some concern as there has been a change in the frequency of El Niño events over past decades that may be related to climate change (Cai and Whetton 1999) and the incidence of El Niño events may increase with future global warming (eg Timmerman *et al.* 1999).

The likely expansion or contraction of the wheat industry compared with grazing landuses depended on the future scenario used. Under doubled CO_2 without climate changes, the relative productivity of wheat compared with grazing may increase by around 20% suggesting expansion may be possible. Whereas if warmer temperatures occur as well, there may be a 20% reduction of the ratio of wheat yields against liveweight gain but little change against grass production. The increase in LWG was due to increases in the growing season of the native grasses with increases in minimum temperatures and rainfall (Hall *et al.* 1998). However, GRASP doesn't simulate the effects of increased heat stress on livestock and this may restrict LWG in these regions leading to lower animal productivities than indicated (Howden *et al.* 1999c). Nevertheless, even small reductions in relative productivities compared with the 108-year mean suggests contraction of the wheat industry may be likely.

Decadal and interdecadal climatic variability, such as evident in the IPO record (Power *et al.* 1999) manifests itself in corresponding variability of production. In the early part of the record (1890 to the 1950's) there was a correspondence between peaks in the index values and periods when productivity was low. However, over the past four decades, the relationship appears to be breaking down as the IPO values are high but productivity is also high. Further statistical analyses of the relationship between El Niño, the IPO and wheat yields is currently being undertaken (Meinke unpub. data). Inspection of the simulated production data show two distinct points of change: the 1950s when variability in grazing system productivity declined and the mid 1970s when variability in wheat yields declined. The latter change appears to be related to changes in ocean circulations and temperatures from 1976 onwards (eg Zhang *et al.* 1998) which appear to have resulted in changes in autumn minimum temperatures and other climate variables in Queensland (McKeon *et al.* 1998).

These results have considerable implications for policymakers dealing with drought issues. The low variability and high productivity of the past few decades are unique in the 108-year record for both grazing and cropping systems. This is likely to have biased the expectations of producers. Return to more normal levels of productivity and variability over the last six years has resulted in claims for 'Exceptional Circumstances' drought support. This study suggests that this has not been an unusually poor period if a decadal view is taken. If a 5-year view is adopted, then on average, the last several years have been the poorest on record for the grazing industry. The worst production periods simulated in the record differ depending on the production element being addressed (ie wheat yield, grass production or LWG) and with the duration being assessed (ie 5, 10 and 20-year windows) as noted by Stafford Smith and McKeon (1999). There exists a challenge to ensure that industry and government policy-making effectively uses such information.

5. ACKNOWLEDGEMENTS

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