

in reduced *Safe CC* (–2% to –10%) especially under the warmer drier scenario depending on location (–14% to –29%). The combined scenarios resulted in changes of –12% to +18% in *Safe CC* across rainfall scenarios and locations.

In central-west Queensland there was considerable amplification of the ±10% rainfall change (–25% to +23%) and strong positive effects of doubling CO₂ (30%). Increased temperature had a negative effect depending on location (–12% to –19%) and the combined change scenario effects ranged from –9% to +49% across rainfall scenarios and locations.

For the site in the south-west, *Safe CC* had the highest sensitivity to the ±10% changes in rainfall (–30% to +35%). Doubling CO₂ and warmer temperatures resulted in strongly positive effects (30% and 25% respectively) and hence there was a very wide range of possible effects across the combined scenarios (+15% to +115%). These effects reflect the major limitations of moisture and temperature on C₄ grass growth in the south-west region.

Discussion

A major finding in this study was the mitigating effect of CO₂ on the combined negative effects of lower rainfall and warmer temperatures on *Safe CC*. This study also showed strong interactions between location and climate change scenarios. To some extent this is to be expected given that there is considerable variation in where and when pasture growth is limited by nitrogen, moisture or temperature. The application of the same climate change scenario across the 12 regions showed that there are both 'winners' and 'losers' in terms of safe carrying capacity and the potential for amplification of small climatic changes.

Potential global change impacts on C₃–C₄ grass distributions in eastern Australian rangelands

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Introduction

In the rangelands of eastern Australia, livestock productivity is influenced by the proportion of C₃ and C₄ grasses in the sward (Wilson & Minson 1980). The proportion of C₄ grasses (measured as percentage of native grass species within regional floristic lists) declines strongly with declining spring and summer temperatures (Hattersley 1983). Temperature and other climatic elements are likely to change in the future due to ongoing human activities such as the burning of fossil fuels. Henderson *et al.* (1994) suggested that global warming of 4°C may result in the 50% C₄ isoline moving southwards by about 250 km. The latitude where the frequency of C₄ species is 90% may move southwards by up to 500 km in eastern Australia.

Changes in CO₂ concentrations affect water use efficiency of grasses and, in the case of C₃ species, photosynthetic rates and nitrogen use efficiency (e.g. Lutze & Gifford 1999) and these could also be expected to affect the relative distributions of C₃ and C₄ species. Ehleringer *et al.* (1997) have assessed implications of altering CO₂ on the 'temperature crossover point' for quantum yields of C₃ and C₄ plants based on a simple physiological

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Day *et al.* 1997) parameterized to represent three generic functional groups (cool climate C₃, warm climate C₃ and C₄ grasses) to develop a relationship between floristic representation and C₃ and C₄ functional group biomass production for eastern Australian rangelands. We then evaluate global change scenarios.

Methods

Growing season (Sept–April) temperatures were calculated from historical data (1958–1988) for 31 sites distributed across the eastern Australian rangelands (Fig. 1). The GRASP model was parameterized using mean values from the predominantly C₄ pastures across northern Australia (160 site-by-year sets of pasture growth measurements). Whilst there are considerable data to support C₄ parameterizations, there are few equivalent data for native C₃ grasslands. The temperature response functions of the cool and warm C₃ groups were altered to optima of 15–25°C and 18–30°C respectively. The minimum nitrogen content (i.e. the N% where nitrogen dilution stops growth) was assumed to be 0.88% compared with 0.68% for C₄ grasses. We did not change transpiration efficiency nor potential regrowth rates of C₃ groups, due to lack of information. Average annual biomass for each functional group was simulated using climate data for 1958–1988. The C₃ functional group with greatest simulated biomass at each site was then used to calculate a growth index (C₄/C₃ biomass) which was regressed against observed %C₄ frequency interpolated from Hattersley (1983).

The simulation studies were a factorial combination of current CO₂ and doubled CO₂ (700 ppm) and temperature change of 0 or 3°C applied to maximum, minimum and dewpoint temperatures. Modifications to GRASP to simulate doubled CO₂ response for C₄ grasses and for C₃ grass transpiration followed those of Howden *et al.* (1998), and changes in radiation use efficiency and leaf critical nitrogen content for C₃ species were based on Reyenga *et al.* (1998). The impact of CO₂ increase on minimum nitrogen contents has rarely been studied and hence is not well known. Wheat and some cultivated grasses show no discernible change in this parameter (e.g. Conroy & Hocking 1993), but a recent study of a native C₃ grass indicated a substantial decline when CO₂ was doubled (Lutze & Gifford 1999). We thus ran the doubled CO₂ scenarios with this value set firstly to current levels (0.88%), and secondly reduced by 25% so that it was the same as the C₄ grasses.

Results

Mean growing season (Sept–April) temperature was 20.5°C at the sites where 50% of grasses were C₄; this is similar to the crossover point based on quantum yields. The location of the isoline where the growth index equals 1 corresponds closely with the northernmost extent in Queensland of the rangelands with a significant C₃ component (Fig. 1). However, the position of this line is likely to change with C₃ parameterization as more data become available. The percent C₄ species in the native flora was related curvilinearly with the growth index (G) $C_4\% = 95.59(1 - e^{-2.918G})$, $R^2 = 0.84$, $P < 0.0001$.

Southwards movements of the two isolines, for growth index = 1 and 50% C₄ frequency, occurred under the doubled-CO₂ scenario (approx. 150 km), the doubled-CO₂+3°C scenario (approx. 250 km) and +3°C scenario (approx. 100 km) and there was a corresponding increase in C₄% in the southern regions especially under the scenarios with temperature increase (Table 1). In contrast, in the scenarios in which increased CO₂ was assumed to reduce the minimum nitrogen content, there was a northwards movement of the growth index isoline (approx. 250–300 km), but the movement of the 50% C₄ isoline varied with scenario, being slightly (approx. 100 km) northward under the doubled-CO₂ scenario but substantially southward under the doubled-CO₂+3°C scenario.

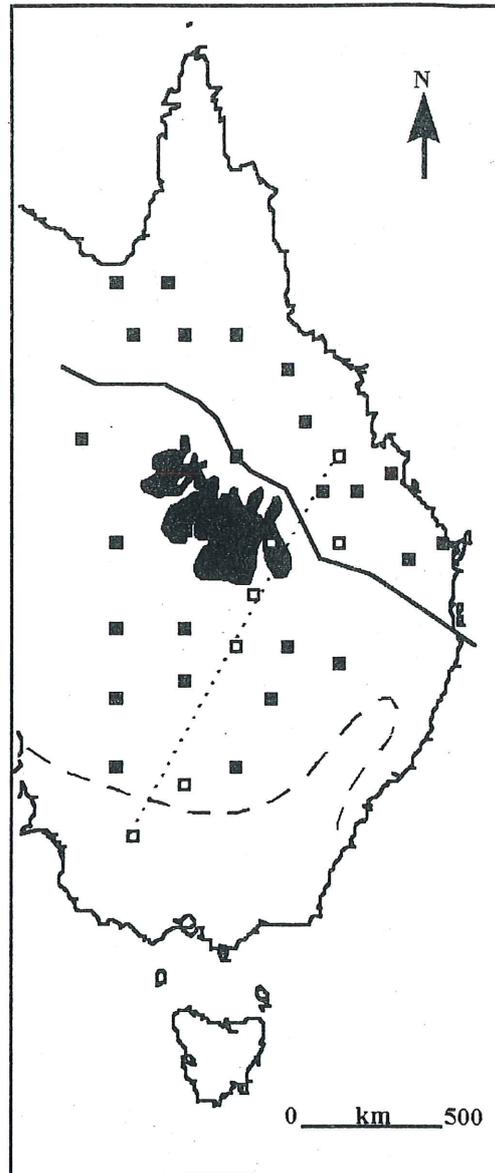


Fig. 1. The eastern Australian rangelands showing the line where growth index equals 1 for the current climate and CO₂ levels (solid line), the mulga lands which are the northernmost extent of grasslands with a significant C₃ component in eastern Australia (shaded area) and the existing 50% C₄ isoline from Hattersley (1983) (dashed line). The transect in Table 1 is represented by the dotted line (included sites □; other sites ■).

Discussion

The 50% C₄ isoline occurs close to where it is predicted to occur on the basis of relative quantum yields for current CO₂ concentrations. However, the quantum yield approach does not incorporate effects caused by seasonality of rainfall or nitrogen dynamics which, we hypothesize, result in significant C₃ representation in communities occurring far north of this point. We used a simulation approach to incorporate these factors in calculating a growth index. The observed northern boundary of where C₃ grasses contribute substantially to native pasture production corresponds to a line with a growth index of 1, suggesting a bioclimatic component to current distributions. Major differences in soil–species–grazing management associations occur in this region and hence possible bioclimatic effects may be overridden by these non-climatic factors. Improvement of C₃ parameterization is required before further direct comparison of growth of functional types can be made.