Integrating global change impacts on native pastures in the Burnett Region of Queensland.

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Abstract Increases in atmospheric concentrations of greenhouse gases such as carbon dioxide (CO_2) are likely to impact on grazing industries through both direct effects on plant growth and through possible changes in climate. Assessment of the likely direction and magnitude of these impacts requires development of appropriate modelling capacities linked with experimental work. This paper documents the adaptation of an existing soil-pasture-livestock model, GRASP, to simulate system responses to changes in CO_2. The adapted model is then used to compare these responses under current climate and CO_2 conditions with four possible future scenarios - 1) doubled CO_2; 2) doubled CO_2 and increased temperature; 3) as in the previous scenario but with a drier climate; and 4) as in 2) but with a wetter climate. These studies suggest that CO_2 changes alone are likely to have beneficial effects, with increased pasture growth, increased and less variable liveweight gain, and increased ground cover. However, subsoil drainage is likely to increase. Growth responses to CO_2 are likely to be greater in drier years than in wetter years partly due to nitrogen limitations in the soils of the region. Increases in temperature in combination with CO_2 further increased animal production due to the increased number of growing days in the cooler months. The increased rainfall scenario had few additional positive effects but further increased subsoil drainage. In contrast, the drier scenario had reduced plant and animal production when compared with current conditions even though seasonal transpiration efficiency was increased by 20%. These results are compared with a similar study of wheat grown in the same region and approaches to integrate the impacts of global change are discussed.

1. INTRODUCTION

Since pre-industrial times, atmospheric CO_2 concentrations have increased 28% from 280 parts per million volume (ppm) in 1800 to 358 ppm in 1994 (Houghton *et al.* 1996) mainly as a result of human activities such as burning fossil fuels and landuse change. Further increases in atmospheric CO_2 concentrations will occur with predictions for the year 2100 ranging from about 480 ppm to over 800 ppm depending on the economic, resource use and population scenarios used (Houghton *et al.* 1996). Increasing atmospheric concentrations of CO_2 are likely to have significant impacts on plant production and through this on livestock production and resource sustainability. This impact will be through both the 'carbon dioxide fertilisation effect' where increased CO_2 concentrations enhance plant growth as well as through climate changes. This study investigates these impacts on grazing in south-east Queensland as part of a larger study looking at global change impacts on Australian agriculture.

The response of plants with C_3 photosynthetic pathways (cool season grasses in southern Queensland, most forbs, trees and shrubs) to increasing CO_2 has been extensively reviewed (e.g. Kimball *et al.* 1993, Poorter 1993). Controlled environment studies generally demonstrate both increased photosynthetic rates (about 20-30%) and reduced stomatal conductance although there is variation in the degree of response and some exceptions have been reported (Poorter 1993). These changes result in increased biomass accumulation through both enhanced assimilate supply and increased water use efficiency. However, there is strong interaction with other variables such as temperature, soil moisture and soil nutrient availability. Hence, there remains considerable uncertainty as to the degree to which the potential enhancement will occur, particularly given the low nutrient status of natural ecosystems as exists in northern Australian grazing lands.

The majority of tropical Australian grazing lands have C_4 grasses as the dominant component of understorey vegetation (Hattersley 1983, Hattersley and Watson 1992) with the mulga lands providing an important exception. The impact of increased CO_2 concentrations on C_4 grasses is less well documented than for C_3 plants. Poorter (1993) reviewed existing experimental data and found an average increase of 28% in dry matter production for C_4 species (compared with 71% for C_3 species) with doubled CO_2. This increase was due to improved water use efficiency as there was no significant difference in assimilation rates. However, some recent studies have shown moderate increases in photosynthetic rates in response to increasing CO_2 (Hunt *et al.* 1996, Morgan *et al.* 1994) whilst others have shown none (Ghannoum *et al.* 1997, Nie *et al.* 1992a, Kirkham *et al.* 1991), or even reduced photosynthetic rates in moist conditions (Nie *et al.* 1992b). The increased photosynthesis reported with enhanced CO_2 under water limiting conditions (Nie *et al.* 1992b, Nie *et al.* 1993) may be due to wetter soil profiles from more conservative water use.

The improvement in water use efficiency under high atmospheric CO_2 levels is likely to be the most significant effect on C_4 pasture grasses. Increases in water use efficiency in such situations occur as a result of reduced stomatal conductance reducing moisture loss while the increased atmospheric CO_2 levels maintain internal CO_2 concentrations and thus photosynthesis. Increases in water use efficiency of up to 36% have been found in field conditions (Ham *et al.* 1996, Owensby *et al.* 1993, Nie *et al.* 1992b, Kirkham *et al.* 1991, Morgan *et al.* 1994, Read and Morgan 1996) with these effects being reduced in wet years (e.g. Knapp *et al.* 1993). However, in some circumstances, the increase in leaf temperature caused by reduced transpiration (Morison and Gifford 1984, Kirkham *et al.* 1991, Nie *et al.* 1992b, Ham *et al.* 1996) may feedback to increase water use as suggested by Hunt *et al.* (1996) although several field studies have recorded higher soil moisture contents in elevated CO_2 treatment plots (e.g. Nie *et al.* 1992b, Nie *et al.* 1993). These findings are potentially significant as they suggest the possibility of more conservative soil moisture usage in pastures and thus an increase in the number of 'green days' and hence liveweight gain (McCown 1981), particularly if the trend of increasing autumn minimum temperatures continues (McKeon and Howden 1993).

The longevity of enhanced growth responses to increased CO_2 concentrations has been raised as an important issue. There remains some uncertainty as to the mechanisms involved in this 'acclimation' process and the degree to which it may occur in the field. Hunt *et al.* (1996) and Morgan *et al.* (1994) studying intact grassland communities and Ghannoum *et al.* (1997) with glasshouse trials have found evidence of photosynthetic acclimation but report that the stomatal responses appeared to be more stable than the photosynthetic responses. Long-term acclimation (as evidenced by reductions in stomatal density over periods of decades) may result in improved response under drought conditions (Woodward 1987).

Improved resilience to drought conditions under conditions of high CO_2 may also result through reducing the effects of increasing vapour pressure deficit (VPD). For example, Seneweera *et al.* (1997) studying the C_4 grass *Panicum coloratum* found that enhanced levels of CO_2 offset the impacts of high VPD and low soil water with high levels of CO_2 maintaining higher leaf water potentials. Similar results have been found in other studies (e.g. Nie *et al.* 1992b, 1993).

The above processes suggest potential increases in plant production in Australian tropical grazing lands with increasing CO_2 concentrations. Increased grass production provides the opportunity to reduce soil erosion by increasing plant cover and to increase feed availability for livestock. However, increased CO_2 may decrease plant nitrogen concentrations (e.g. Hunt *et al.* 1996) which may reduce liveweight gains in those situations where nitrogen limits feed intake and thus growth (Hendricksen *et al.* 1982). In situations where liveweight gain is not limited by nitrogen content of feed, increased non-structural carbohydrate levels at high CO_2 concentrations may result in increased weight gains. However, Hungate *et al.* (1997) found no effect of increased CO_2 on nitrogen concentration in cool season rangeland annuals suggesting no change to animal nutrition and intake. Hence, there remains a considerable need for additional research on this issue.

Enhanced plant growth under elevated CO_2 levels may result in alterations to the relative competitive abilities of species in tropical grasslands. For example, Polley *et al.* (1994) suggest that increased CO_2 levels may have been associated with increased shrub invasions in US savannas during this century due to increased competitive abilities of C_3 shrubs over the C_4 grasses. This issue is particularly pertinent in Queensland given the existing issue of managing woody weed invasions and regrowth from cleared areas. Archer *et al.* (1995) and Burrows (1996) have shown that management effects such as pasture burning are likely to dominate the ecosystem response and that climate and CO_2 effects are likely to be of secondary importance.

The possibility of changes in the ratio of C_3 and C_4 grass species has also been raised (Carter and Peterson 1983). However, Owensby *et al.* (1993) and Nie *et al.* (1992c) found no evidence that increased CO_2 concentrations significantly changed grass species composition with community structure providing a strong buffering capacity. Nevertheless, there remains the possibility that changes in partitioning to roots and shoots (Rogers *et al.* 1994) or changes in seedhead production (Ghannoum *et al.* 1997) may result in long term changes. Changes in disturbance regimes may also affect community composition although Wilsey *et al.* (1994) found no effect of elevated CO_2 on regrowth rates or allocation patterns in the one African shortgrass savanna species (*Sporobolus kentrophyllus*) that they studied.

A major problem facing the grazing industry is to make reasonable predictions of how increases in CO_2 and climate change will interact. The challenge is to extrapolate the physiological knowledge gained on a limited number of species under artificial growing conditions to the complex semi-natural ecosystem of native pastures of northern Australia. Our approach is to use a currently operational model of pasture and animal production (GRASP; Littleboy and McKeon 1997) and examine to what extent it can be modified to represent CO_2 effects. Such an approach builds a logical and repeatable pathway to the future.

2. SIMULATING CO_2 EFFECTS

2.1 Description of GRASP

GRASP is a model simulating the above-ground yield of a sward dominated by perennial native grasses. GRASP includes a four layer soil water balance model which calculates the processes of run-off, drainage, soil evaporation, tree and grass transpiration dry matter flow, nitrogen uptake, pasture management effects (i.e. stocking rate and pasture burning) and plant density (i.e. perennial grass basal cover). GRASP calculates growth as a function of grass transpiration, radiation interception and regrowth potential. The model has been parameterised for over 40 native pasture communities in Queensland and has been derived from the results of over 50 years of field experimentation and grazier experience. Descriptions of the model development include Rickert and McKeon (1982), McKeon *et al.* (1982), Hendricksen *et al.* (1982) and McKeon *et al.* (1990). A full description of each equation is given in Littleboy and McKeon (1997) and evaluation, calibration and validation are described in Carter *et al.* (1996) and Day *et al.* (1997).

GRASP includes models of the other processes of dry matter flow, i.e. senescence (death of green material), detachment, trampling, and litter breakdown and grazing effects and changes in perennial grass basal cover. In this preliminary analysis we have yet to consider the effects of CO_2 increase and climate change on these other flows in the grazing system. However, given the generality of parameters for these processes across a wide range of climates it is reasonable to concentrate on plant growth.

The modelling approach used in GRASP has both benefits and limitations in simulating CO_2 effects on plant production. The benefits are that the model has been parameterised for a wide range of native pasture communities, soils and locations, and is operational in simulating grazing trials, grazing properties and statewide drought alerts. The model structure is generally compatible with physiologically based crop models (e.g. Hammer and Muchow 1994) simulating plant growth as an interaction of radiation interception, transpiration, temperature, VPD and nitrogen availability. However, GRASP does **not** simulate: individual species/varieties in the sward; root growth; phenological development; nor the variable partitioning of net-photosynthate between roots and shoots in perennial plants. Partitioning varies with species, phenology, grazing history and soil water. Given the lack of data for native pastures, GRASP has been parameterised, calibrated and validated with only above-ground sward yields.

2.2 CO_2 effects on growth, water use and nitrogen parameters in GRASP

To simulate pasture growth under enhanced CO_2 levels, there is a need to adjust several parameters in GRASP. The key parameters are those relating to radiation interception, transpiration and nitrogen dynamics.

The evidence reviewed previously suggests that radiation use efficiency (RUE) does not increase in the long term in C_4 grasses. Theoretical models (eg Chen *et al.* 1993) suggest an increase in net photosynthesis of 4-10% for a doubling of CO_2. For a doubling of CO_2, we assume an increase of RUE by 5%. However, we note that Walker *et al.* (unpublished data) have measured substantial increases (13-60%) in photosynthetic rate for two native C_4 grasses at elevated CO_2.

Decreases in stomatal conductance for C_4 and C_3 species with increasing CO_2 are well documented. Reviews of available data suggest that doubling of CO_2 concentrations increases water use efficiency, calculated over the seasonal growth period of 100-180 days, by an average 30 to 40%. Similarly, instantaneous measurements of transpiration efficiency (TE: μ mol CO_2 s^{-1} per mmol H_2O m^2 s^{-1}) show that large increases are possible (30-150% for a doubling of CO_2). Despite these increases in instantaneous TE, most studies show that total seasonal water use does not change substantially with increasing CO_2, probably due to increased leaf area. Hence we expect GRASP to simulate little change in seasonal water use, but increased green cover and increased seasonal transpiration efficiency expressed as plant growth per mm of seasonal transpiration. Based on the measurements for tropical grasses (L. Walker *et al.* unpublished data) and reviewed data we initially use here a 40% increase in TE for doubled CO_2.

Transpiration is reduced in GRASP by changing the relationship between green yield (DM kg/ha) and the ratio of potential transpiration to potential evapotranspiration (ET). Thus changes in the TE parameter must be linked to parameters describing the above relationship. However, the relationship between green yield and proportion of radiation intercepted should not change. To achieve this effect in GRASP, the parameter, green yield at 50% relative transpiration, which describes the relationship between green yield and the ratio of potential transpiration to potential ET is changed in the same proportion as transpiration efficiency. Thus, for a 40% increase in CO_2 concentration, the green yield required to produce the same potential transpiration is also increased by 40%. Hence with these linked changes in TE and 'yield cover', daily transpiration is reduced but growth is not.

The experiment of L. Walker *et al.* (unpublished data) provides data specifically on the response of two northern Australian tussock grasses to increased CO_2 under weekly defoliation. Doubling CO_2 increased regrowth rate by 10% on average. Other studies on young plants and theoretical analysis support this order of magnitude response (Agren 1994).

Modelling studies (eg Sellers *et al.* 1996) and experimental data referred to earlier suggest that the above effect of reducing daily transpiration with increasing CO_2 could increase surface temperature above that due to CO_2 effect on radiative forcing. In GRASP the effect of reducing transpiration on leaf surface temperature could be represented by re-calculating daily temperature, vapour pressure deficit and potential evapo-transpiration (e.g. Class A pan) which have been input from the daily climate file.

The effect of transpiration on ambient temperatures and VPD was examined using a spatial version of GRASP (Carter *et al.* 1996) simulating Queensland's grazing lands for one month in the summer growing season (January). For similar solar radiation conditions (21-24

$MJ/m^2/day$) multiple regression relationships between monthly averages of solar radiation and VPD changed with monthly evapo-transpiration (soil evaporation and grass transpiration). From this analysis it was calculated that reduction in monthly evapo-transpiration of 20% (eg from 60mm to 48mm) results in a 0.4°C increase of average temperature and maximum temperature; 1.2 hPa increase in VPD; and 0.4mm increase in potential ET (i.e. Class A pan). However, even in January in the middle of the 'wet' season, monthly rainfall is well below potential ET, and hence it is unlikely that changing daily TE and daily transpiration as indicated above will actually change monthly ET and the driving climate variables at a monthly or seasonal time scale. Sensitivity studies indicated small effects of the above CO_2 changes on seasonal ET. Hence, currently we do not represent any effect of changing CO_2 on daily climatic inputs.

GRASP includes relationships between senescence (death of green material) and frost and soil water. Of particular importance is the relationship between maximum possible green cover and soil water availability. Measurement of leaf area of maize under increasing water stress showed that about 50% higher leaf area could be maintained under high CO_2 (Gifford 1988) at a given soil moisture level. This was similar to change in stomatal conductance, and hence we assume in GRASP that the green cover able to be supported for a given level of soil water changes in proportion to transpiration efficiency, i.e. 40% increase in this case.

Analysis of 160 year x site combinations of regularly burnt or mown exclosures across Queensland by comparing a calculated nitrogen (N) index (following Parton *et al.* 1988) with measured nitrogen yield has indicated a general plateau of N yield of about 20-25 kg N/ha for undisturbed native pastures (McKeon *et al.* 1997). This plateau of total seasonal N uptake can be reached by the middle of the growing season with subsequent favourable conditions not significantly increasing further uptake (e.g. Norman *et al.* 1963). Increases in soil moisture under enhanced CO_2 appear to have increased nitrogen mineralisation in mediterranean ecosystems (Hungate *et al.* 1997) and increased temperatures are also likely to increase mineralisation rates (Parton 1988). However, the incorporation of a soil carbon:nitrogen model into GRASP may be needed before these effects can be adequately simulated and at this stage the parameter maximum above-ground N uptake per year is not changed with increasing CO_2.

In GRASP, the rate of N uptake, before maximum uptake is reached, is parameterised as kg N/ha per 100 mm of transpiration (3-10 kg N/ha per 100 mm) depending on location and species. Reduced transpiration with increased CO_2 will reduce rate of N uptake in this case. However, reduced uptake and increased mineralisation conditions are likely to lead to increased N concentrations in soil water, and hence increased rate of uptake per mm of transpiration. Sensitivity studies showed that a 20% increase in this parameter for doubled CO_2 resulted in approximately the same rate of N uptake as occurred in ambient conditions (e.g. Hungate *et al.* 1997).

GRASP uses a critical % N in dry matter to calculate a nitrogen index (NI) used to limit radiation use efficiency and regrowth. C_4 grasses are able to continue above-ground growth with concentrations of nitrogen as low as 0.4 to 0.8 % N in dry matter with variation relating to differing leaf/stem ratios. Any changes in leaf/stem partitioning with enhanced CO_2 levels will thus influence plant critical nitrogen levels as well as affecting potential dry matter production through changes in nitrogen use efficiency. However, data for northern Australia native grasses (L. Walker *et al.* unpublished data) do not indicate substantial changes in proportion of stem and in other tropical grasses the effects are inconsistent with both decreases (Seneweera *et al.* 1997) and increases (Ghannoum *et al.* 1997) observed. Changes in the concentrations of Rubisco in leaves under high CO_2 levels have been frequently measured and there is some experimental evidence (e.g. Rogers *et al.* 1996) that this reduces critical leaf nitrogen contents in crop plants although little evidence of the same effect in tropical grasses. Considering the above, no change is made in critical nitrogen concentrations with CO_2.

The availability of young green leaf in native pastures is one of the major driving variables of steer liveweight gain (Ash *et al.* 1982) through the effects of diet selection for leaf and diet nitrogen concentration (Hendricksen *et al.* 1982). The effect of CO_2 change and climate change on soil water and temperature will be captured by this indicator of annual liveweight gain. However, possible changes in pasture composition (Henderson *et al.* 1994) in response to climate change and CO_2 increase are yet to be considered.

The above review has examined in detail the necessary changes to parameters in GRASP to represent the effects of doubled atmospheric CO_2 (Table 1). Many of the changes are dependent on current research on response of native grasses and trees to CO_2. It is vital that research on those species important to the productivity of Australia's grazing lands is continued to be supported so that prediction of impact of future changes can be made.

Table 1 Parameter values changed in GRASP for current (1 * CO_2) and doubled CO_2 (2 * CO_2) scenarios for the Burnett region.

GRASP parameters	**1CO_2**	**2CO**
Potential regrowth (kg/ha/day)	15.0	16.5
Potential regrowth /unit grass basal cover	3.5	3.85
Transpiration efficiency (kg/ha/mm @ 20hPa)	13.5	18.9
Green yield at which potential transpiration is 50% of potential ET	1000	1400
Rate of N uptake ()kg N/ha per 100 mm transpiration)	6.0	7.2
Radiation use efficiency (kg/ha per MJ/m^2)	12	12.6

Day *et al.* (1997) has parameterised GRASP for several sites in the Burnett region. Parameter values for the typical black speargrass-*Aristida-Bothriochloa/* communities in the Burnett region for the major driving relationships (as described above) and their changes under enhanced CO_2 levels are shown in Table 1. The validation graph (Fig. 1) shows that the model is simulating pasture growth effectively under current conditions.

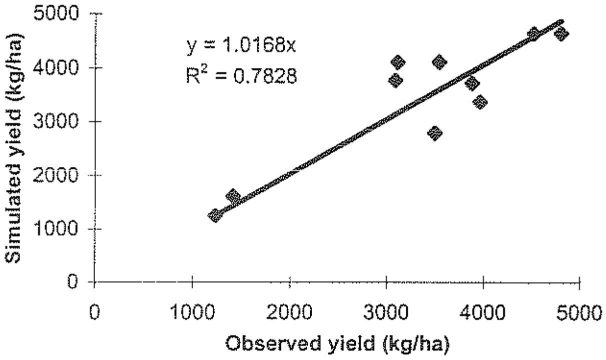

Figure 1 Observed vs simulated above ground biomass for 'Ronnies Paddock' site, Brian Pastures Research Station, Burnett region for years 1987-96.

3. EXPLORATORY STUDY

GRASP was used with the above parameter changes to explore possible outcomes from a range of global change scenarios for Gayndah. The CO_2 and climate scenarios were; 1) current climate + CO_2 (350 ppm); 2) current climate + doubled CO_2 (700 ppm); 3) temperature increase (+2.76°C) + 700 ppm CO_2; 4) reduced rainfall (-24% summer, -12% winter) + temp. change + 700 ppm CO_2; and 5) increased rainfall (+12% winter) + temp. change + 700 ppm CO_2. These scenarios are named 'Baseline', 'CO_2', 'Warm', 'Warm/Dry' and 'Warm/Wet'. These scenarios are drawn from the CSIRO 1996 scenarios as described in Reyenga *et al.* (1997) and were used to modify the historical climate record from 1957 to 1996. Grazing management was to adjust stocking rates in June of each year to use 30% of available pasture over the next six months.

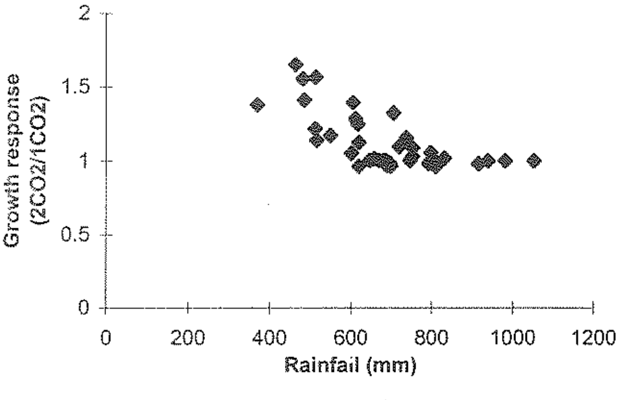

Figure 2. The growth response to enhanced CO_2 (ratio of $2CO_2/1CO_2$) with rainfall for a native pasture in the Burnett region for years 1959 to 1996.

4. RESULTS

Doubling of CO_2 concentration was simulated to have significant impacts on soil hydrology, plant growth and animal production. Mean seasonal transpiration efficiency was increased by about 10% as a result of both reductions in transpiration (-2%) and increases in growth (8%). Reduced transpiration and runoff enhanced soil moisture status, increasing through-drainage by 20% (Table 2). The growth response to enhanced CO_2 was greatest during dry years, showing up to 65% increases when compared with current CO_2 levels (Figure 2). Runoff was decreased due to increased mean dry matter levels and higher minimum cover (61%: Table 4). Increased dry matter levels and small increases in growing days (1%) resulted in both increased animal production per hectare (10%) and a markedly reduced coefficient of variation of stocking rates (-27%). However, growth was nitrogen-limited in these simulations with seasonal nitrogen uptake reaching its maximum several times and this possibly restricted expression of variability. The 6% increase in the mineralisation index suggests that nitrogen supply might change under these scenarios more than was simulated here allowing more growth to occur.

Table 2 Mean annual transpiration (mm), runoff (mm) and drainage (mm) for the baseline conditions and mean % change from baseline for the four scenarios.

Scenario	Transpiration	Runoff	Drainage
Baseline	*399*	*19*	*20*
CO_2	-2	-21	20
Warm	0	-11	20
Warm/Dry	-28	-53	-65
Warm/Wet	4	-11	50

Table 3 Mean total standing dry matter (kg/ha/year), liveweight gain (kg/ha/year) and the coefficient of variation (%) of the stocking rate for the baseline conditions and mean % change from baseline for the four scenarios.

Scenario	Growth	LWG/ha	CV of SR
Baseline	*4516*	*75.4*	*36.1*
CO_2	8	11	-27
Warm	7	19	-10
Warm/Dry	-13	-12	40
Warm/Wet	7	20	-13

The scenario with both increased CO_2 and temperature (Warm) tended to remove some of the effects of the CO_2 change alone resulting in smaller increases in transpiration efficiency (7%) and drainage. However, compared with the baseline results, simulated animal production increased markedly (19%) due to increases in the number of growing days in the cooler months (13%). Similarly, the 27% increase in mineralisation index suggests that additional nitrogen could become available under such conditions, reinforcing the need to better simulate processes affecting nitrogen availability.

Table 4 Mean percentage of days with growth index greater that 0.05, minimum standing dry matter and mean mineralisation index for the baseline conditions and mean % change from baseline for four scenarios.

Scenario	%GI days	SDM min.	Mineralisation
Baseline	*81*	*324*	*62*
CO_2	1	61	6
Warm	13	-13	27
Warm/Dry	9	-15	8
Warm/Wet	13	71	31

The two scenarios with altered rainfall in addition to the CO_2 and temperature changes showed varying responses. The Warm/Dry scenario showed a 21% increase in seasonal transpiration efficiency and significantly reduced runoff and drainage compared with the baseline. Under this global change scenario, the positive effects of CO_2 and temperature on animal production are negated. The Warm/Wet scenario shows small increases in seasonal transpiration efficiency (3%) but retains most of the positive response to the CO_2 and temperature change. Drainage is increased substantially (50%) compared with the baseline conditions.

5. DISCUSSION

CO_2 and climate change impacts

This simulation study has certain caveats which have important implications for interpretation. The major purpose of the study was to evaluate how an empirical operational pasture model such as GRASP could be modified to reasonably simulate the effects of CO_2 and climate change scenario. The CO_2 effects have been derived from recent studies of elevated CO_2 effect in growth chambers and or glasshouse studies on tropical grasses. Thus, this study represents our first attempt to link modelling to physiological studies. Similarly, the studies with climate change scenarios represent our first attempt to evaluate alternative representations of climate change and their interaction with doubled CO_2. However, it must be remembered that we have evaluated only an 'average' native pasture **without** trees and the climate change data are small samples (38 years) of possible climate change representations. Nevertheless, the simulation results using the above representation of CO_2 effects highlight:

1. the beneficial effects on plant growth of doubling CO_2 in arid climates and dry years and the mean increase in soil moisture observed experimentally;
2. the effects on plant growth are likely to lead to increased animal production through increased pasture productivity, length of growing season, reduced variability and greater opportunities for pasture burning;
3. erosion may be reduced due to lower runoff and increased ground cover but increased drainage may pose problems where there are salinity and waterlogging risks; and
4. nitrogen limitations on plant growth may restrict the beneficial impacts of increased CO_2.

This study suggests that empirical models such as GRASP can be plausibly modified to include the effects of CO_2 as measured in growth chambers and glasshouses once measurements for relevant species and appropriate conditions (low nutrient availability, high VPD, and frequent water stress) are available. However, the parameter changes made to represent the effects of doubled CO_2 were derived from short term (i.e. seasonal) growth chamber experiments. Longer term studies using open-topped chambers are required to determine whether these effects are permanent responses to elevated CO_2. Nevertheless, the above preliminary simulation analysis indicated that the potential beneficial effects are worthy of further research.

The simulations are limited by lack of knowledge of the impact of CO_2 on additional processes operating in complex semi-natural ecosystems such as grazed native pastures. For example, the effects of climate change and management on nutrient cycles, especially nitrogen and phosphorus, will play a large role in limiting or amplifying the effects of CO_2 increase. Furthermore, the effect of the interaction of pasture community attributes with increased CO_2 is yet to be considered.

The simulated liveweight gain per hectare provides only an indication of change in animal production for several reasons including the large number of options available given variation in animal type (sheep, cattle), product (wool, calves, steers, cows), breed (e.g. *Bos indicus, Bos taurus*) and management. Furthermore, the nutritional effect of digestibility, leaf/stem ratio, species composition, availability of browse, landscape driven redistribution of runoff, soil mineral limitations such as phosphorus, and compensatory gain have yet to be considered. In addition, Howden and Turnpeny (1997) suggest that under the global warming scenario used here, the frequency of heat stress days will increase markedly (by about 140%) in cattle in the Burnett region. Despite these caveats we consider that the dominating impact of global change will be on plant growth which drives the animal productivity of the grazing system (Day *et al.* 1997);

Explicit modelling of the whole soil-plant-animal production-management system is now required to examine to what extent changes in plant growth and variability translate into changes in economic performance.

Integrated global change impact assessment

Global change impacts on production and economic performance of the grazing industry are not going to happen in isolation from other agricultural pursuits. Landuse decisions are likely to include the relative profitability and risk of other activities. In the Burnett region, cropping is an alternative landuse on some land units. Reyenga *et al.* (1997) have assessed the impacts of the same global change scenarios used here on wheat cropping in the Burnett. Comparison of their results and the current study suggests that if CO_2 changes occur in the absence of climate change or with a wetter climate, then there may be an increase in wheat cropping in the Burnett. However, if rainfall either remains the same or decreases and warmer temperatures occur, then grazing may replace some wheat cropping in the region. Full integration of these landuse change effects would require both spatial modelling of the respective systems with a socio-economic component to the analysis as well as simulation of fluxes of greenhouse gases to determine feedback effects on the global changes. An additional component of such studies would require assessment of the impacts of global change on pests, weeds and diseases

6. ACKNOWLEDGMENTS

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