
THE PROCEEDINGS OF THE
NEW ZEALAND SOCIETY
OF
ANIMAL PRODUCTION
VOLUME 62 2002

Impact of potential change in climate and atmospheric concentration of carbon dioxide on pasture and animal production in New Zealand

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ABSTRACT

A mechanistic model was used to measure the impact of changes in climate (temperature, rainfall and solar radiation) and a 75% increase in the concentration of atmospheric carbon dioxide on pasture and animal production on eight representative New Zealand lowland farming systems. The climate changes increased annual pasture dry matter production per hectare by 10-30%, assuming no changes in pasture composition. A 75% increase in CO_2 concentration increased pasture production by around 40%. Together, climate change and increased CO_2 concentration increased yields by 50-77%. In all cases, the seasonal distribution of pasture production was not greatly affected. Both climate change and increased CO_2 concentration individually increased annual milk production per hectare by around 24%, lamb meat and beef by around 30% and wool by around 22%, under the constant farm management systems selected. The increases in production were mainly due to increases in stocking rate resulting from the increased pasture production, but increased conservation and feeding out of hay were required. The model predicted an increase in lamb growth rates. Milk, meat and wool production was higher under climate change than under increased CO_2 concentration in Southland, but the opposite was true in northern New Zealand. The combined effect of climate change and increased CO_2 concentration was greater, with potential increases over the two scenarios averaging 52% for milk, 57% for lamb and beef and 46% for wool.

Keywords Climate change, carbon dioxide, greenhouse effect, dairy, sheep, beef, pasture, temperature, rainfall.

INTRODUCTION

Over the past 160,000 years, atmospheric carbon dioxide concentration has varied between 180 and 350 ppm. Before industrialization, atmospheric CO_2 concentration was around 280 ppm. Since then it has increased by 25%, to be now over 350 ppm, and is currently increasing by around 1.5 ppm/year (Houghton and Woodwell, 1989; Royal Society of New Zealand, 1988). CO_2 is one of the gases that absorbs the infrared energy being radiated from the Earth into space, and traps this radiated energy in the lower atmosphere - the greenhouse effect. The annual rate of increase in concentration of all the gases that contribute to the greenhouse effect, including CO_2, methane, nitrogen oxides and chlorofluorocarbons (CFC's), is 2.2 ppm. If this rate is sustained, the concentration of CO_2 would double in around 65 years time (2055), and the concentration of all greenhouse gases would double in around 45 years time (2035).

The effect of this increase in concentration of CO_2 and other greenhouse gases is the subject of much debate (e.g. Reifsnyder, 1989), although the consensus amongst meteorologists is that the increase will lead to a warming of the world's climate by 0.3°C per decade (Houghton *et al.*, 1990).

The effect of an increase in greenhouse gas concentrations on the New Zealand climate is uncertain, as most climate models operate on too coarse a scale to specifically identify New Zealand. However, by using regional scale outputs from these general circulation climate models, together with data from recent and geological changes in New Zealand's climate, Salinger and Hicks (1990a) have developed two scenarios of what New Zealand's climate might be in 2050 A.D. These two climate scenarios are based on two rates of global warming. Scenario 1, the 'most likely scenario',

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is based on the period of maximum warmth 8-10,000 years ago, and results in New Zealand temperatures averaging 1.5^{o}C warmer than present, with lighter westerly winds. Scenario 2, the 'alternative warm scenario', is based on the currently considered upper limit to greenhouse warming, and results in temperatures averaging 3^{o}C warmer than present. Scenario 2 is coupled with the La Nina phase of the El Nino-Southern Oscillation (Graham and White, 1988), resulting in frequent incursions of tropical air from the north. The two scenarios also produce increases or decreases in rainfall and solar radiation depending on region (Salinger and Hicks 1990b).

Salinger *et al.* (1990) have outlined the impacts that an increased concentration of CO_2 of 500 ppm and the climates outlined in the scenarios of Salinger and Hicks (1990a) may have on New Zealand animal industries in 2050 A.D. They concluded that impacts on productivity and seasonal pattern of production of pasture was expected to have a greater effect on animal production than direct impacts on animal metabolism and performance.

To quantify some of the effects that an increased concentration of CO_2 and the Salinger and Hicks (1990a,b) climate scenarios would have on pasture production and subsequent animal production, the Ministry for the Environment commissioned the Ministry of Agriculture and Fisheries to undertake a simulation study to model pasture and animal growth under changed climate and CO_2 concentrations (Korte *et al.*, 1990). This paper summarizes some of the results of that study.

METHOD

Components of the Model

The model, developed from McCall (1984), is a simulation model of a grazing system written in Fortran with a daily time step. The major components of the model are:

Pasture production

Daily pasture growth rates are determined from a relationship between daily intercepted radiation, photosynthesis and crop growth rates. This relationship is modified by air temperature, soil moisture, soil fertility, leaf area index and the reproductive status of the plant. The green dry matter produced senesces at a rate that depends on crop mass and soil moisture, and the dead material decays at a rate determined by temperature, rainfall and soil moisture. The model is currently restricted to a mainly ryegrass-white clover pasture.

Intake and utilisation of dry matter by grazing livestock

Pasture intake is calculated daily and depends on pasture mass, allowance and quality, grazing duration, and animal age, liveweight and physiological status. Metabolisable energy is used as thebasis for animal production, and is allocated between maintenance, growth, pregnancy, lactation and wool. This allocation depends on such factors as feed availability, heat loss, time of year, age and weight of the animal, its physiological status, number of foetuses or lambs, and stage of gestation or lactation. Calculations are done daily.

There are 3 livestock enterprises:

(a) **Sheep :** This models the breeding ewe flock and includes subsections for growth, pregnancy, lactation and wool growth. Ewes, hoggets, ram lambs and ewe lambs are modelled separately. The model is restricted to Romney sheep.

(b) **Beef :** This is a simpler model restricted to calculation of the energy requirements for the growth of fattening steers for up to twelve months. The model currently does not cater for bull beef or two age groups of fattening cattle.

(c) **Dairy :** This model includes growth and lactation subsections. Pregnancy is restricted to its effects on milk production. Rearing of replacements is not included.

Management variables

The model allows set stocking and rotational grazing; adjustment of stocking rate and rotation length; the closing of paddocks and making of hay from surplus pasture when pasture mass exceeds predetermined levels, and feeding it back when pasture mass falls below predetermined levels; feeding of supplementary energy when animal weights fall below predetermined levels;

TABLE 4 Effect of specific climate changes and increased atmospheric CO_2 concentration on annual production of milk fat, lamb and beef meat and wool per hectare in New Zealand. The change is expressed as the percentage change in milk, meat and wool production at the base climate.

SITE	Waikato	Taranaki	Canterbury dryland	Canterbury irrigated	Southland	Mean
MILKFAT						
Scenario 2	15	11	-	13	39	21
Base + CO_2	46	27	-	14	16	26
Scenario 2 + CO_2	69	49	-	32	72	56
LAMB & BEEF MEAT						
Scenario 2	1	-	40	16	62	30
Base + CO_2	13	-	44	25	39	30
Scenario 2 + CO_2	22	-	81	88	101	59
WOOL						
Scenario 2	-3	-	24	22	28	18
Base + CO_2	20	-	31	32	15	25
Scenario 1 + CO_2 1 + CO_2	32	-	43	59	40	44
Scenario 2 + CO^2	28	-	61	48	49	47

mean. The reduction in summer and autumn pasture production under scenario 2 was due to temperatures exceeding to a greater degree the optimum for temperate pasture growth (Mitchell, 1956).

The combined effects of changed climate and CO_2 concentration on pasture production were either additive (e.g total pasture production in the North Island) or synergistic (e.g total pasture production in the South Island).

Despite the large increases in pasture production, the seasonal distribution of pasture production was not greatly affected. The climate scenarios increased the proportion of pasture produced in the winter by 2% and in spring by 6%. Increased CO_2 concentration increased the proportion of pasture produced in the summer by 3%.

Animal Production

The pasture production part of the model showed that annual pasture production for scenario 1 and scenario 2, at both levels of CO_2 concentration, differed by less than 5%. As not all site/scenario combinations were modelled for Scenario 1, animal production data are only presented for Scenario 2.

Table 4 lists predicted mean effects of climate change and increased CO_2 concentration on animal production. Sheep and beef meat data are combined, as they partially substitute for each other depending on the ratio of sheep and cattle numbers. The major points were:

(i) Increases in milk, lamb and beef meat and wool production of up to 50% occurred under both climate change and increased CO_2 concentration, due mainly to increased pasture growth and hence carrying capacity. In some cases, there was also increased production per head of up to 40%, reflecting restrictions imposed by the selected management systems on performance under current climates. The size of the increase in milk, meat and wool production was higher under the climate change scenario in Southland, and higher under increased CO_2 concentration in northern New Zealand.

(ii) Higher stocking rates were often necessary to take full advantage of increased pasture growth, and were up to 54% higher for sheep and beef for the combination of climate change and increased for the current climate.

Climate Scenarios

Changes in mean annual temperature, annual rainfall and sunshine hours under each scenario for each site (Table 2) were derived from Salinger and Hicks (1990b). Base temperatures and sunshine hours were amended on a daily basis, and rainfall at each rainfall event.

TABLE 2 Change in mean annual temperature, mean annual rainfall and sunshine hours at the farm sites under the two climate scenarios (derived from Salinger and Hicks 1990b).

Site	Scenario 1			Scenario 2		
	Temp	Rainfall	Sunshine	Temp	Rainfall	Sunshine
Waikato	+1.2°C	+10%	-5%	+3.0°C	+12%	0
Taranaki	+1.3°C	+15%	-5%	+3.2°C	-5%	+2.5%
Winchmore	+1.8°C	-5%	+8%	+3.0°C	0	0
Southland	+1.8°C	-5%	+3%	+3.0°C	-5%	+3%

RESULTS AND DISCUSSION

Pasture Production

The difference in pasture production between sites within islands was relatively minor (Korte *et al.*, 1990), so Table 3 gives the mean results for each island.

Results from the model show that the direct effect of increased atmospheric CO_2 increased pasture production more than the climate changes in either scenario 1 or scenario 2. Increased CO_2 concentration had little effect on pasture production in winter, but raised it considerably in summer.

The climate scenarios greatly increased pasture production in winter and spring, but had little effect in summer and autumn. The increase in winter and spring pasture growth rates and annual pasture production was twice as large in the South Island. The climate effect was mainly due to the increased temperature, as the changes in rainfall (5-10%) in Table 2 were small compared with present annual variations. For example, in Canterbury rainfall can vary from around 25% to 2 times the long term mean (Cherry, 1989). Annual temperature is also variable, but to a lesser extent, with annual temperatures up to 1.5°C above or below the

TABLE 3 Effect of climate change and increased CO_2 concentration on seasonal pasture growth rates (kg/ha/day) and annual pasture production (kg/ha) meaned over the North and South Island sites. The numbers in brackets are the percentage change from present pasture production. Base is the climate used to calibrate the model. Seasons are winter: June-August, spring: September-December, summer: December-February, autumn: March-May.

	Winter	Spring	Summer	Autumn	Total
NORTH ISLAND					
Base	11.6	59.6	36.9	22.2	11850
Scenario 1	13.7 (18%)	68.2 (15%)	38.0 (3%)	22.2 (0%)	12930 (9%)
Scenario 2	17.3 (49%)	78.5 (32%)	32.1 (-13%)	20.0 (-10%)	13470 (14%)
Base + CO_2	12.0 (3%)	81.3 (38%)	57.8 (57%)	29.9 (35%)	16540 (40%)
Scenario 1 + CO_2	14.5 (24%)	93.8 (58%)	57.3 (55%)	29.3 (32%)	17730 (50%)
Scenario 2 + CO_2	19.2 (65%)	110.2 (85%)	47.2 (28%)	27.5 (24%)	18530 (57%)
SOUTH ISLAND					
Base	6.0	44.4	42.5	18.3	10100
Scenario 1	10.0 (67%)	61.1 (38%)	45.7 (7%)	21.0 (15%)	12530 (24%)
Scenario 2	11.7 (96%)	68.9 (55%)	44.2 (4%)	20.1 (10%)	13180 (31%)
Base + CO_2	5.5 (-7%)	58.5 (32%)	65.1 (53%)	23.0 (26%)	13820 (37%)
Scenario 1 + CO_2	9.8 (64%)	83.2 (87%)	68.1 (60%)	26.5 (45%)	17040 (69%)
Scenario 2 + CO_2	11.5 (93%)	93.2 (110%)	66.0 (55%)	25.5 (40%)	17830 (77%)

and buying and selling of sheep and beef cattle at predetermined dates and weights or numbers. Greenfeed or root crops are not accommodated by the model.

Validation of the Model

The sheep model was validated against southern North Island hill country farming systems by McCall (1984), and the dairy model against Taranaki Research Station data by N.D. Barlow (*pers. comm.*). The beef model has not been validated but was constructed from feed tables (e.g. ARC, 1980; Drew and Fennessy, 1980) and Whatawhata Research Centre data (e.g. Bircham and Sheath, 1986) by D.G. McCall (*pers. comm.*).

TABLE 1 Sites, model run (years), r^2 between predicted and actual monthly pasture yield, farming system simulated and reference for actual pasture data.

Location	Model run (years)	r^2	dairy	sheep	sheep plus beef	Reference
Rukuhia (Waikato)	6	0.62	X			Baars, 1976
Hawera (Taranaki)	10	0.96	X		X	Judd *et al.*, 1990
Winchmore (Canterbury)						Rickard and McBride, 1986
dryland	13	0.98		X		
irrigated	13	0.99	X		X	
Mona Bush (Southland)	8	0.93	X	X		Radcliffe, 1974

Animal production was modelled at four sites: Hamilton (Waikato), Hawera (Taranaki), Winchmore (Canterbury) and Mona Bush (Southland). At Winchmore, both irrigated and dryland farming systems were examined. For each site, model pasture production was tested against actual production over the years that actual production data were available (Table 1). Soil water holding capacity, soil fertility index, flowering date, and the relative efficiencies of reproductive to vegetative growth were adjusted to obtain the best fit between model pasture production and actual pasture production from mowing trials at each site.

To allow the impact of higher CO_2 concentrations on pastures to be studied, response functions of photosynthesis to radiation and temperature at different concentrations of CO_2 from Overdieck and Bossemeyer (1985) were added to the model. Rate of photosynthesis was calculated for both current (taken to be 345 ppm) and enriched (600 ppm) CO_2 concentrations to obtain a CO_2 enrichment factor, i.e. photosynthesis rate at enhanced over current CO_2 levels. The effects of radiation and temperature in the functions resulted in the average enrichment factor varying with time of year (winter 0.9-1.1, summer 1.3-1.5) and latitude (Auckland 1.29, Invercargill 1.17).

Ministry of Agriculture and Fisheries farm consultants were asked to supply farm management and production data for typical farms of the type being modelled at each location. Production data was also obtained for an irrigated farmlet at Winchmore Research Station. The model was set up to mirror as closely as possible the farm management systems used, and the output data compared with the actual farm performance data supplied.

Four dairy farms, two sheep farms and two beef and sheep farms were modelled (Table 1). The dairy farms were all factory supply, and did not milk cows in the late autumn-early winter. The Canterbury Irrigated and Southland sheep farms bred their replacements, whereas the Waikato and Canterbury Dryland farms did not. The Waikato and Canterbury Irrigated sheep farms had beef cattle, but these were a minor enterprise on the Canterbury farm. Rotational grazing was practised in all farming systems, except for breeding ewes between lambing and weaning. Full details of the grazing systems are given in Korte *et al.* (1990).

Differences in output between simulated and supplied data were less than 12% for milk production, 6% for meat production and lambing percentage, just under 20% for wool production, and 4% for stocking rate.

Stocking Rate

Stocking rate was increased by 1.0, 1.1, 1.2, 1.3, 1.4, 1.6, 1.8 and 2.0 for each combination of climate and CO_2 concentration to find the optimum stocking rate under the selected grazing management regime. The optimum stocking rate at each site was taken to be the stocking rate at which production of milk or lamb meat per hectare was maximized, provided that the balance of hay conserved to hay consumed and the amount of supplementary feed used remained at the levels predicted

TABLE 5 Effect of climate change and increased CO_2 on variability (standard deviation for the number of years the model was run at each site) of annual production of milkfat and lamb and beef meat per hectare in New Zealand. The change is expressed as the percentage change in variability of livestock production from the variability at the base climate.

SITE	Waikato	Taranaki	Canterbury dryland	Canterbury irrigated	Southland
Years model run	6	10	13	13	8
MILKFAT					
Scenario 2	-33	11	-	-27	-86
Base + CO_2	-33	27	-	0	52
Scenario 2 + CO_2	-41	48	-	-19	67
LAMB & BEEF MEAT					
Scenario 2	-14	-	115	133	42
Base + CO_2	14	-	153	242	35
Scenario 2 + CO_2	51	-	175	247	51

CO_2 concentration. No increase in stocking rate with increased pasture production sometimes resulted in increased production per animal, but a smaller increase in production per hectare compared with increasing stocking rate, or even a decrease in production.

(iii) There was little or no effect on lambing percentage. Lambs grew faster and reached sale weights earlier, reflecting the large increases in pasture growth rates in spring and summer, which were not fully compensated for by the increased stocking rate under the grazing systems used in the model. Lambs sold at the final sale of the season were also heavier.

(iv) Variability of production was calculated for milk and meat production, the two parameters used to determine optimum stocking rate. Increased milk and meat production was often accompanied by increased variability of production, more than twice as variable in Canterbury for sheep and beef (Table 5). However, for some sites, variability was decreased. Increased variability of production required considerably greater quantities of conserved feed, over twice as much in some cases (Table 6).

Whether these increases in animal production would be achievable in practice depends on a number of factors (Martin *et al.*, 1990), such as:

(a) *- pasture species remaining constant.*
The site specific parameters used in the model reflected the pasture species composition at the time pasture growth was measured. The predictions assume no change in species composition. The validity of this assumption is not known. There is evidence of a spread southwards of more tropical C4 pasture grasses, such as paspalum, possibly due to climate warming (Field and Forde, 1989). However, Newton (1991) claims that under higher, unspecified, CO_2 concentrations, this spread could be reversed, as the advantage in growth of sub-tropical C4 grasses over temperate C3 grasses at higher temperatures would be considerably reduced, due to the C3 photosynthetic pathway being considerably more responsive to changes in CO_2 concentration than the C4 photosynthetic pathway. The balance between herbs (including clover) and grass could also be altered at higher CO_2 concentrations. These changes will alter both the productivity and the nutritive value of the pasture.

TABLE 6 Effect of climate change and increased atmospheric CO_2 concentration on annual production of hay. The change is expressed as the percentage increase over hay made at the base climate.

SITE	Waikato	Taranaki	Canterbury dryland	Canterbury irrigated	Southland	Mean
DAIRY						
Scenario 2	43	11	-	*	79	44
Base + CO_2	94	26	-	*	28	54
Scenario 2 + CO_2	114	37	-	*	136	96
SHEEP + BEEF						
Scenario 2	103	-	47	0	310	115
Base + CO_2	32	-	59	167	124	96
Scenario 2 + CO_2	165	-	103	193	512	243

* no hay made under this management system

(b) - change in the incidence of pasture pests and diseases or animal pests, parasites and diseases. Pasture and animal health problems are expected to increase in a warmer climate, particularly if accompanied by increased rainfall (Salinger *et al.*, 1990), and could therefore reduce productivity. The impact of increased CO_2 on animal health problems is unknown.

(c) - other factors associated with climate change or increased CO_2, such as decreased availability of irrigation water or increased likelihood of flooding.
Also any change in severity or frequency of extreme events, such as cyclones and winter storms may affect pasture and animal performance.

(d) - advances in agricultural research and technology, which may minimize any adverse effects and maximize the benefits of climate change and increased CO_2.
The model is based on current technology. As the climate scenarios are set for 60 years in the future, it is likely that, if the current pace of technological change is maintained, farming practices and systems could be very different to those of today.

(e) - the profitability of livestock enterprises. There are likely to be increases in pasture and animal health costs, feed conservation costs, and also fertilizer costs to realize the increased pasture productivity, and these may partially offset the increase in animal production.

(f) - farm managers either unable or unwilling to cope with the increased risks associated with greater seasonality and variability of production, through the greater conservation of feed, or more flexible production systems.
Results have been presented for the optimum stocking rate for milk or sheep production per hectare. This reflects the situation where output per hectare is maximized at the expense of production per head. In practice, farmers are likely to compromise between the two, to ensure production of lambs of a certain grade or to reduce variability of production, particularly in more marginal environments.

The milk, meat and wool industries are heavily export oriented. Thus whether the predicted increases in milk, meat and wool production will be achieved will depend on how global economic factors are reflected back on New Zealand product prices. These economic factors may partly reflect the impacts of climate change and increased CO_2 concentration on New Zealand's customers and competitors for animal products.

The potential impact of the results of the model need to be viewed with caution due to uncertainties associated with the climate change scenarios (see Martin, 1989). These include:

1. Any effect of seasonal or annual changes in variability of temperature and rainfall.

2. Feedback mechanisms that may reduce or enhance the greenhouse effect, such as changes in cloud cover, polar snow and ice cover, and ocean heat uptake (Dickinson, 1989).

3. Other atmospheric phenomenon, such as the El Nino-Southern Oscillation (Graham and White, 1988).

However, Salinger and Hicks (1990a) point out that the scenarios were only developed as an indicator of what New Zealand's climate might be in 60 years time, provided certain climatological assumptions hold true. The scenarios were specifically designed to allow preliminary sensitivity studies, such as the study reported here, of the type and magnitude of responses of sectors of the New Zealand economy to any change in climate.

CONCLUSIONS

The climate change scenarios and increases in CO_2 concentration produced large increases in pasture production. These resulted in increased milk, meat and wool production due mainly to increased stocking rates. However, the seasonal distribution of pasture growth was not greatly changed, so that increased conservation of feed was required to realize the potential gains resulting from pasture growth. There are reservations about whether the increases in pasture production or animal output depicted by the model will occur, but the results of our simulations do show that changes in climate or CO_2 concentration could have major effects on the productivity of New Zealand's livestock industries.

ACKNOWLEDGMENTS

We thank the Ministry for the Environment for funding this research project.

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