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# Modelling the direct effects of a potential enhanced greenhouse effect on Australian agriculture

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## 1. Introduction

The atmosphere's natural "greenhouse" properties, which create ambient temperatures suitable for Earth's plant and animal populations, has been intensified by human activities resulting in emission of greenhouse gases such as carbon dioxide, methane and chlorofluorocarbons. The continued release of "greenhouse" gases (GHG) into the atmosphere is predicted to increase the capacity of the atmosphere to capture incoming solar radiation. The potential consequences of this "enhanced" greenhouse effect (EGE) include increased atmospheric and ocean temperatures, changed rainfall patterns, and consequent effects on plant and animal life.

There has been intense interest in examining appropriate responses to the projected EGE (e.g. in Australia, as exemplified by the Industry Commission's recent inquiry concerning GHG (Industry Commission 1991)). In this paper are reported initial investigations into an examination of the effects of an EGE on Australian agriculture. The concern in Section 2 is to outline an appropriate research method for investigating EGE issues in the context of Australian agriculture; key issues here are uncertainty and the nature of Australian agriculture. It is concluded that general equilibrium modelling is required to explore EGE consequences for Australian agriculture, and it is proposed to use ORANI for this analysis. In Section 3, therefore, there is presented a review of projected production impacts of an EGE on Australian agriculture, couched within the ORANI framework.

## 2. Research method: uncertainty, Australian agriculture economics

### 2.1 Uncertainty

There are three fundamental EGE uncertainties concerning an EGE and Australian agriculture. Knowledge of the predicted EGE event is based on the best available modelling contained in the General Circulation Models. These models contain uncertainties because the structure of the global climate system is not known, and therefore cannot be modelled, with certainty; and/or because modelling may be restricted by computing constraints. A second EGE uncertainty concerns observation of its occurrence. Existence of an EGE could be determined when its "signal" emerges from climatic "noise" which is expected by about 2030 AD. The converse, however, is not true. If observed temperatures have not exceeded the upper bound by 2030 AD, this may be the consequence of episodic climate cooling temporarily dominating the temperature-increasing effects of an EGE. There are also no direct observations of the impact of the predicted general global warming on the environment generally, on the ecology sustained by this environment nor, particularly, how the impacts of any EGE-induced changes on environment or ecology would affect human society and especially its economic system (Godden 1992).

Where there is serious uncertainty about the future this uncertainty becomes an integral feature of the decision-making. A formal decision theory approach is adopted here. Future climate regimes can be most simply represented by supposing that there are only two possible future events - an EGE (E) and no global warming (E*) - with associated, subjective, non-zero probabilities p(E) and p(E*). A decision-maker could plan around this uncertain future, taking action e (appropriate if an EGE were to emerge) and e* (appropriate if no EGE emerged), with R(k|j) being the net return of action k (=e,e*) when the actual event turns out to be j (=E,E*) (cf. Godden 1991). There are four possible outcomes:

Table 1: Possible Outcomes of Economic Decision Making

| | Future State of Nature | |
|---|---|---|
| GHG Adaptation Strategy | no EGE (E*) | EGE (E) |
| no GHG adaptation (e*) | R(e*\|E*) | R(e*\|E) |
| GHG emissions reduced (e) | R(e\|E*) | R(e\|E) |

Various decision rules could be implemented for choosing the better strategy, based on these expected net returns and their associated probabilities. The simplest, for example, would be to compare the expected return from the strategies e and e*.

Quantitative analyses of policy making in an EGE context have generally proceeded by comparing the two elements in the first column of Table 1 - i.e. evaluating the cost of EGE-adaptation strategies relative to no action which implicitly assumes that an EGE will not occur, that is p(E)=0 (e.g. Marks et al. 1989, Industry Commission 1991). This approach solves a relatively trivial economic and policy problem: i.e. what is the cost of implementing a greenhouse adaptation policy on the assumption that forecasts about an emergent EGE turn out to be wrong. While there are obvious uncertainties about both the emergence and effects of an EGE, and the date at which we could know that global warming is certain, given the current state of scientific knowledge it is clearly ludicrous to assume that the probability of an EGE is zero.

If it is assumed that $p(E) \neq 0$, the economic modelling of the two elements in the last column of Table 1 is a far-from-trivial problem. Such analyses require predictions of the effect of an EGE on the structure of the economy. In the present context, such analyses require predictions of the effect of an EGE on Australian agriculture.

## 2.2 Agriculture

The projected EGE may have a direct economic impact on Australian agriculture through its effects on natural resources used in farming. Some of these effects include CO2 availability, ambient temperature, rainfall and wind; and their effects on farm production characteristics such as yield, land degradation, changes in associated flora (indigenous and exotic species) and fauna (indigenous, and exotic species both husbanded and feral), and "scourges" (pests, diseases and weeds) (Godden and Adams 1992).

These direct effects are not, however, the only potential economic consequences for Australian agriculture of the projected EGE (Godden and Adams 1992). Other possible issues include:

Direct effects

Effects of an EGE on *natural resources* will be substantially conditioned by management response, including changes in husbandry practices and enterprise mix as a consequence of the effect of an EGE on the natural environment. Of major importance to management will be changes, if any, in production variability.

Indirect effects

1. As well as environment-induced *management responses* arising from an EGE, there may be changes in production costs (including input prices), changes in farm structure, "scourges", and product demands which will affect husbandry practices, enterprise mix and output levels.

2. *Changes in demand* for Australian agricultural produce may be as important as - or even more important than - domestic production effects. Since Australian agriculture is heavily export-oriented, these demand effects will be principally externally generated and have two main components: the global demand for products (and their substitutes and complements); and other countries' supplies of these products; both may be affected by an EGE.

3. Socio-economic consequences of an EGE also include collective *policy responses* to a projected EGE. Policy responses likely to affect Australian agriculture are of both domestic and external origin.

. *Domestic* policy responses to an EGE include allocative efficiency responses (e.g. changing investment and dis-investment decisions in publicly-provided infrastructure) and distributive responses (e.g. changing direct subsidies, or provision of subsidised infrastructure, in response to the effects of an EGE on particular groups). A second domestic policy response includes economic management decisions, such as the direct and indirect impacts of EGE-mitigating policies (e.g. carbon taxes or emission quotas), and macroeconomic responses that might affect the level of aggregate domestic demand, interest rates and exchange rates.

. Possible *external* policy responses mirror domestic responses. Of most direct consequence from Australia's perspective are other countries' policies that affect the export demand for Australian agricultural produce:

> . If an EGE adversely affects developed countries' agriculture in the northern hemisphere, then these governments are likely to respond by increasing their levels of agricultural protection.
>
> . The domestically-perceived export demand for Australian agricultural products is a function of the exchange rate as well as the overseas demand for these products. Imposition of direct or indirect constraints on greenhouse gas emissions outside Australia - e.g. carbon taxes - may affect Australian exports of energy-intensive products, and indirectly affect Australian agriculture through exchange rate effects.

### 2.3 Economic modelling

An EGE may affect Australian agriculture directly through its effects on the agricultural production process. If an EGE has major effects on Australian agriculture, these effects may have second round impacts through, for example, the level of exports and consequent exchange rate effects. The "agricultural" effects of an EGE on Australia are, however, not solely generated within the agricultural sector. If an EGE and/or policy responses to an EGE affect non-agricultural sectors closely integrated with agriculture or economic variables important to agriculture, apparently-remote effects of an EGE will be transmitted into agriculture. These considerations indicate that general equilibrium is the appropriate modelling framework to conduct an EGE "experiment" concerning Australian agriculture. In the present project it is proposed to use ORANI (Dixon et al 1982) for this analysis; preliminary analysis has already been undertaken (Godden and Adams 1992). The objective of the present paper is to outline modelling of the direct production effects of an EGE on Australian agriculture in an ORANI context.

The modelling outlined below ignores, however, many serious issues that may arise as a consequence of an EGE in Australian agriculture. Although uncertainty about the existence of an EGE was used to justify the modelling framework (Table 1), other aspects of uncertainty are ignored. For example, only point estimates of EGE impacts were sought, when clearly these are drawn from subjective probability distributions with potentially large variances. The relationship between the intensity of an EGE and its agricultural effects is assumed to be continuous, whereas an EGE may induce discontinuous and irreversible changes, particularly in plant and animal ecology (Godden 1991).

## 3. Modelling agricultural effects

For the single output firm, impacts of an EGE may be modelled as changes in the production relationship. If an EGE is uniformly favourable (unfavourable) to production, then an EGE will be comparable to disembodied technological progress (regress) and may be modelled by shifts in the location of production isoquants. These changes may be Hicks-neutral or Hicks-biased. Possible biological interpretations of such changes include:

. Hicks-neutral changes. If an EGE simply resulted in uniformly more (or less) growth of all desirable plant species because of higher rainfall with no other effects, then output would increase (or decrease) in a Hicks-neutral way. Agricultural production changes in response to input price changes would be similar to the non-EGE regime, but at different levels.

. Hicks-biased changes. Continuing the previous example, if an EGE brought greater plant growth of desirable species because of higher rainfall, but fertiliser was leached more rapidly from soils, then an EGE would result in a Hicks-biased form of technological regress, and would be fertiliser-saving. Thus, for unchanged relative prices of inputs, the production system would use relatively more (less) of the inputs advantaged (disadvantaged) by an EGE.

As well as affecting the location of the isoquants, an EGE may also change the elasticity of input substitution. Such changes are important because they would affect the flexibility of farm response to changes in input prices. If the elasticity of input substitutability increased (decreased) with an EGE, the production technology would become more (less) responsive to changes in input prices. Consider a biological interpretation in terms of the substitutability of machinery and labour: suppose substitution of machinery for labour occurs through the use of larger/heavier machinery. If an EGE is accompanied by higher rainfall then, on heavier soils, larger machinery may become relatively less suitable because of increased compaction in generally wetter soil conditions, with accompanying yield reductions. The elasticity of substitution of machinery for labour would be reduced, indicating less opportunities for substituting machinery for labour as the price of machinery falls relatively to labour. Alternatively, for similar reasons, wetter conditions may change the substitutability between land-based machinery and aerial machinery: if generally wetter conditions favour plant growth, but land-based machinery leads to increased soil compaction, then an inwards shift of isoquants primarily at relatively high levels of use of aerial inputs would increase the elasticity of substitution between land- and air-based machinery.

If an EGE leads to biased technological change which, for a particular input, is input-saving for some input combinations but input-using for other combinations, then the enterprise effects of an EGE will be considerably more complex. The post-EGE isoquant map will intersect pre-EGE isoquants and the consequences for relative input use for constant relative input prices will be more difficult to determine. These problems will be exacerbated if elasticities of substitution among inputs also change with an EGE.

Since Australian farms usually produce more than one product, it is preferable to model them as multiple-output, multiple-input firms. This framework may also be used to examine regional production effects. Analogous to previous arguments, the potential impact of an EGE on the mix of outputs and inputs in multi-product firms or regions may be represented by Hicks-neutral or Hicks-biased technological progress or regress, and/or by changes in the elasticity of substitution among inputs and outputs.

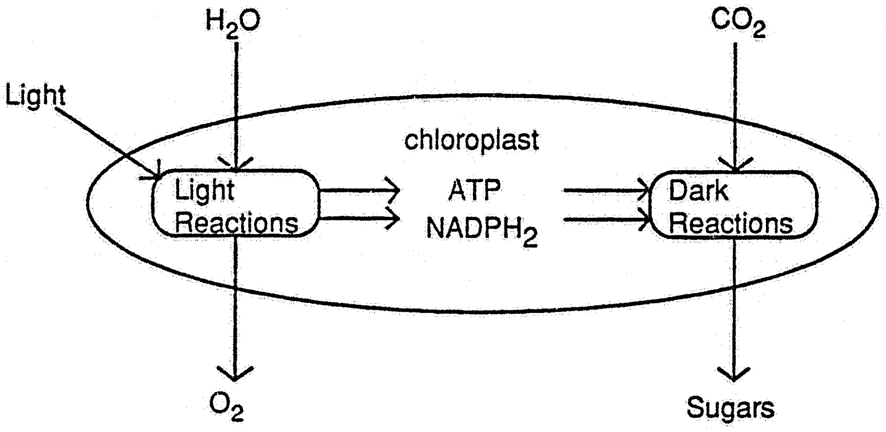
## 4. Direct Impacts

### 4.1 CO2 Availability

(a) Effect on Plant Growth: The increasing atmospheric concentration of CO2 is expected to have a significant effect on global biomass production. The primary effects of high CO2 are an increase in photosynthetic rate and a decrease in transpiration rate. The response in photosynthetic rate differs between plants with C3 photosynthetic pathways (temperate species) compared with those with C4 pathways (tropical species). The reason for this stems from the different 'dark reactions' in the chloroplasts of C3 and C4 plants.

Figure 1 illustrates the reactions that take place in a chloroplast. The ATP energy source and the NADPH2 reducing compound produced in the light reaction feed into the Calvin cycle. In the Calvin cycle, CO2 is reduced to starch and sugar - the basic building blocks for plant growth. During this process, a catalyst (RuBP) is produced to react with either O2 or CO2. If it reacts with O2, then carbon is lost from the cycle via photorespiration and therefore, less sugar and starch are produced. If CO2 concentration is high and O2 concentration low, relatively more RuBP reacts with CO2 causing photorespiration levels to fall and starch and sugar production to rise (Acock, 1990).

**Figure 1 - Photosynthetic reactions in chloroplasts**



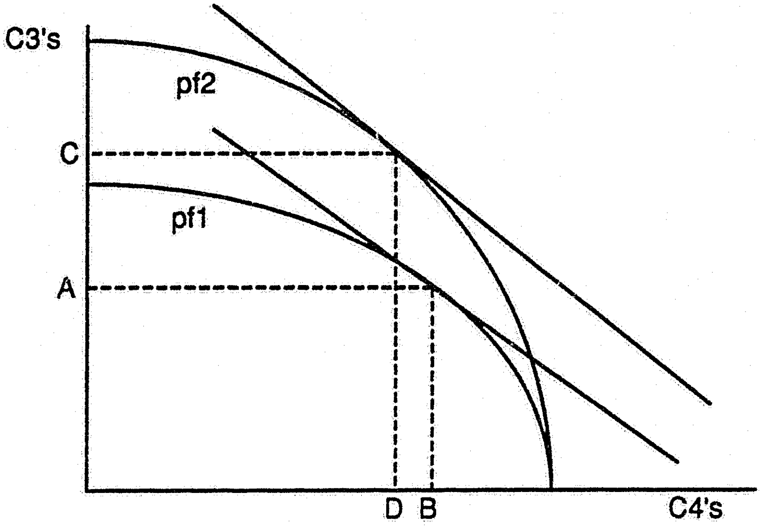
All green plants are capable of this reaction but the process is significantly more efficient in C3 plants because of the composition of the mesophyll cells within which the Calvin cycle occurs. Mesophyll cells allow the easy diffusion of CO2 and O2 through the cell walls. An increase in CO2 concentration is therefore readily utilised resulting in increased activity in the Calvin cycle at the expense of photorespiration. The cells in which the Calvin cycle is carried out in C4 plants (bundle sheath) are separated from the air inside several layers of other cells. For this reason, the diffusion of CO2 and O2 between bundle sheath cells is much slower. C4 plants therefore fix CO2 by a less direct process than C3 plants which puts them at a relative disadvantage in higher atmospheric concentrations of CO2.

High CO2 concentration has also been found to increase the water use efficiency of most crops (Morison and Gifford, 1984; Gifford et al , 1984; Schonfeld, 1989). Water use efficiency is defined as the amount of dry matter accumulated per unit of water taken up or lost by the plant. High CO2 concentration increases water use efficiency by raising stomatal resistance and photosynthetic rate, and lowering the transpiration rate per unit leaf area.

(b) Impact on Production: The greater proportion of commercial plants have C3 photosynthetic pathways. Other factors remaining constant, increased concentration of CO2 would have a positive effect on overall production. The effect of CO2 can be represented as a form of disembodied technological progress that would be Hicks biased in favour of C3 plants. The CO2 "fertiliser effect" is illustrated in Figure 2 by a shift in the production frontier from pf1 to pf2 resulting in an increase in the production of C3 plants (A to C). Whether the CO2 "fertiliser effect" causes a reduction or increase in output of C4 plants will depend on the slope of pf2 at B. The greater the CO2 effect, the more likely the slope at B on pf2 will be greater than slope on pf1.

The CO2 fertiliser effect could also influence output in cereal enterprises. For example, in northern NSW and southern Queensland, wheat and grain sorghum are reasonably close substitutes (ignoring growing season) and therefore have a relatively high elasticity of substitution in production. Increased concentration of CO2 has been found to increase wheat yields (Wong and Osmond, 1991) whilst the response of sorghum has been shown to be relatively weak (McKeon et al, 1988; ESD, 1991). This would have an effect similar to that demonstrated in Figure 2

**Figure 2 - CO2 Fertiliser Effect**



Increased water use efficiency could affect the level of substitution between dryland and irrigated farming practices. As crops use less water per unit of dry matter production, the requirement for irrigation in marginal cropping regions would decline. Laboratory studies by Morison and Gifford (1984) have shown that high CO2 increases the water use efficiency in most of Australia's important commercial crops. Results from the studies ranged from 72% increase in maize to 100% in lucerne, ryegrass and phalaris.

(c) Available Data: The current volume of scientific literature regarding the effect of high CO2 on plant growth is extensive. Glasshouse controlled experimentation has been carried out providing extensive quantitative data on the impacts for agronomic crops. Relationships investigated include effects on partitioning of dry matter, changes in root/shoot ratio, leaf area, transpiration and photosynthetic rate, water use efficiency and overall economic yield.

Further research is required investigating the interrelationship between a potential CO2 fertiliser effect and other growth limiting factors that may be imposed by an EGE. The data contained in Table 2 presents the most recent scientific findings regarding the effects of CO2 on crop yields. Due to the difficulties involved with simulating high atmospheric CO2 concentration in a field environment, it is inconclusive whether the results obtained in controlled glasshouse experiments are an accurate reflection of crop response in the field.

### 4.2. Increased Temperature

(a) Impact on Growth: For most crop and pasture species, the rate of growth and development has been shown to be closely related to the temperature regime in which they are grown. The enzyme reactions that control growth and development processes of plants are limited by low temperatures and at high temperatures, the protein enzymes are denatured. The temperature response of plants tends to mirror that of enzymes and therefore has minimum and maximum temperatures at which plant growth is slow or does not proceed and optimum temperatures at which growth and development are maximised (Ting, 1982).

Degree days or thermal time is the accumulated excess heat above some minimum temperature necessary for crop growth. This determines the length of successive development phases and hence the total growth period. In this way, temperature affects the growing season of plants

**Table 2: Effect of Increased Atmospheric CO2 Concentration:**
**ORANI Classification**
**(a) Pastoral, Wheat Sheep and High Rainfall Industries.**

| Commodity | Pastoral | Wheat Sheep | High Rainfall |
|---|---|---|---|
| Wool | + small [a] | + small [a] | + small [a] |
| Sheep | + small [b] | + small [b] | + small [b] |
| Wheat | 84% [cA]<br>47% [dB] | 84% [cA]<br>47% [dB] | 84% [cA]<br>47% [dB] |
| Barley | 64% [cA] | 64% [cA] | 64% [cA] |
| Other Cereals | 30-50% [cA] | 30-50% [cA] | 30-50% [cA] |
| Meat Cattle | + small [e] | + small [e] | + small [e] |
| Milk & Pigs | + small [f] | + small [f] | + small [f] |
| Sugar/Fruit | 10% [gA] | 10% [gA] | 10% [gA] |
| VCOT | 10-20% [cA] | 10-20% [cA] | 10-20% [cA] |
| Poultry | No effect | - | - |

**(b) Other Agricultural Industries**

| Industry/Commodity | Impact on Production |
|---|---|
| Northern beef/ Meat cattle | + small [e] |
| Milk & pigs/ Milk cattle & pigs | +small [f] |
| Sugar/sugar | 10% [gA] |
| VCOT/VCOT | 10-20% [cA] |
| Poultry/poultry | - |

A - Total dry weight
B - Economic yield

VCOT - Vegetables, Cotton, Oilseeds and Tobacco.

Authors
a - Pittock (1989)
b - NSW Dept. Agriculture (1991)
c - Morison & Gifford (1984)
d - Wang & Hennessy (1991)

e - McKeon (1988)
f - Lottkowitz (1989)
g - Allen (1990)

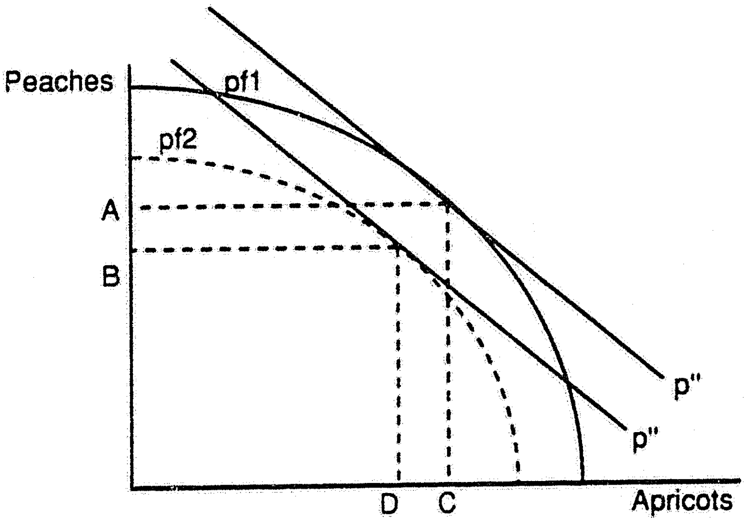
with a given crop or pasture reaching maturity more rapidly as temperature increases.

Temperature also affects plant growth by influencing the uptake of nutrients from soil, the rate of organic matter breakdown and release of soil nutrients such as nitrogen and sulphur. The response to nitrogen fertiliser is also improved as soil temperature rises.

(b) Impact on Production: Increased ambient temperature will have wide ranging effects between different production regions and on the viability of existing enterprises within a given region.

Stonefruits A considerable amount has been written on the potential impact of increased temperature on the winter chilling requirements of pome and stonefruits (Pittock, 1989; Lottkowitz, 1989). The initial impact of increased ambient temperature in, for example, the Goulburn Valley would take the form of Hicks neutral technological regress as it would reduce mean production for all producers. Figure 4 illustrates the shift in output potential for two fruit types from pf1 to pf2 as the reduction in winter chilling units (CUs) causes reduced fruit set and therefore yield per tree.

**Figure 4 - Effect of Increased Temperature on Stonefruits**



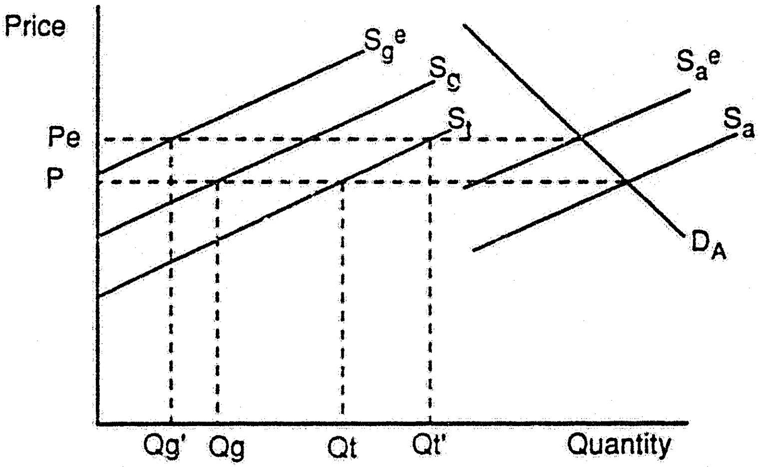
Simulations reported in Pittock (1989) suggest that an increase in temperature of 3°C would reduce fruit set in most growing regions of Victoria by 50%, thereby impacting production to the extent where stonefruits would no longer be viable. Pittock stressed that these calculations were made under a number of crude assumptions. Nevertheless, the results suggest that stone fruit producers in the affected areas may have to diversify into other low-chill enterprises if the year-to-year risk of not having an economic crop is to be minimized.

The current level of substitution between outputs in fruit growing regions is very low due to the long term nature of tree life cycle. In the long term, reduction in viability could increase the elasticity of substitution with other enterprises such as crop and/or pasture-livestock production.

If the potential impact on stone fruit production was to manifest itself in reduced yields, the problem would seem to be only a regional or district one and therefore would not have any significant effect on national output as regions better suited to the production of stonefruits under higher temperatures increase output at the expense of the more marginal regions.

Consider the multi-regional case comparing a potentially marginal producing region (Goulburn Valley) with a colder region such as Tasmania. The Pittock (1989) scenario of a 3°C increase in ambient temperature would benefit producers in Tasmania where winter CUs are in excess supply, and therefore comparatively disadvantage producers in the Goulburn Valley where the accumulation of winter CUs is a limit to production. This is illustrated in Figure 5 by the shift in supply of Goulburn valley stonefruit from Sg to $Sg^e$ reflecting reduced output imposed by higher ambient temperature (Qg-Qg'). Industry supply contracts from Sa to $Sa^e$ forcing price upwards to Pe. Tasmanian producers would respond by increasing output to Qt'.

**Figure 5 - Regional Impact on Stonefruit Industry**



Breeding and subsequent adoption of low-chill varieties may to some extent reduce the potential impact of increased temperature. Continuing the stonefruit example, low chill varieties have been developed for most of the major commercial crops. However, adoption of new varieties by producers will be limited by lower output during the time period required for trees to reach maximum yield potential.

Cereals The potential effects of increased ambient temperature are likely to be less severe on cereal production for a number of reasons. The dominant influence on yield and quality in all growing regions is the amount and timing of rainfall and the prevalence of pests and disease. It is not unreasonable to assume that on-going plant breeding programs will be able to cope with a rise in temperature over the next 40 years of 2-4°C (Climate Impact Group, 1991). This assumption is supported by results from recent trials (Wang and Hennesy, 1991) which have confirmed the ability of wheat cultivars to maintain productivity under increased temperature in a high CO2 environment.

Livestock The impact on livestock production systems could be significant if temperature change increases the number of days each year when animal production is reduced by heat stress. Alternatively, it could have a positive effect by reducing cold stress during the winter months. Ruminant animals have a wide thermoneutral zone in which animal production and food conversion efficiency are independent of ambient temperature. The zone ranges from 10-30°C for most ruminants but varies with the size of the animal and its physiological state. Temperatures outside this range cause ruminants to reduce food intake, which in turn leads to a reduction in live-weight gain, lactation and overall reproductive performance (including fertility of rams and bulls, ovulation rates, oestrus duration and conception rates).

Increased mean winter temperatures may have a positive effect on animal production by reducing maintenance requirements and the incidence of cold stress in new born lambs and off-shears, particularly in southern regions and the higher tablelands and ranges. An increase in mean daily temperatures may also increase the competitive position of African breeds of cattle due to their tolerance of heat stress, thereby increasing elasticity of substitution with traditional British breeds.

(c) Available data: As is the case for all the climatic consequences of increased global CO2 concentration, the accuracy of data relating to the impact of increased temperature on production is to a large extent reliant on the ability of general circulation models (GCMs) to accurately forecast future climate patterns (e.g. Reifsnyder, 1989; Linzen, 1990).

The general consensus amongst climatologists is that current GCMs simulate reasonably accurately seasonal and diurnal patterns of weather and produce fair estimates of latitudinally averaged surface temperatures and rainfall. The area in which current GCMs exhibit their greatest weakness is the prediction of climate change at a regional level - an area of particular importance in determining the effects on agriculture. Table 3 presents the current best estimates of the effects of increased temperature on production.

### 4.3 Changes in Rainfall Patterns

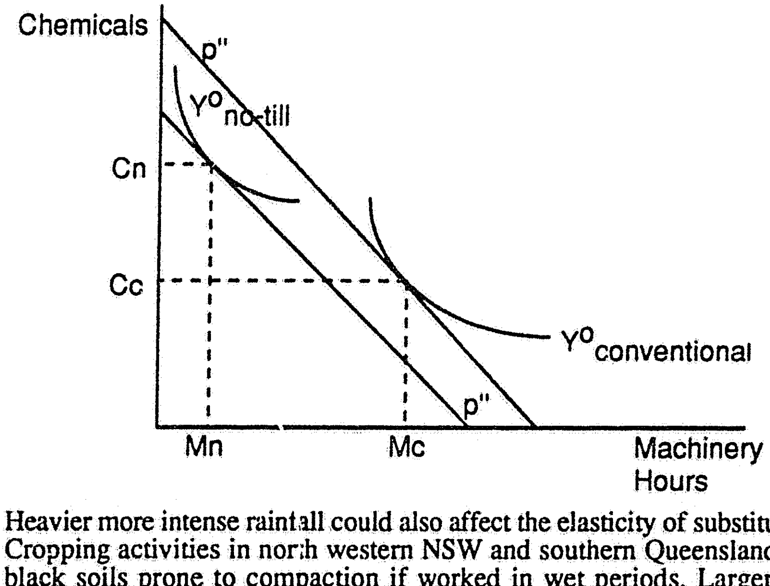
(a) Impact on Production: Climate models have forecast increases in the amount, seasonality, variability and intensity of rainfall. The current predictions for Australian rainfall patterns (Climate Impact Group, 1991) by the year 2030 include:

- average increase of 0-20% in mean rainfall in summer rainfall zone
- monsoon more intense but no movement further south
- average decrease of 0-20% in mean rainfall in winter rainfall zone
- local changes could be twice as large due to topographic effects
- marked increase in magnitude and frequency of heavy rainfall events
- longer dry spells in mid-latitudes

An increase in the amount of rain may cause greater leaching of nutrients from soils, thereby lowering the relative productivity of conventional cultivation methods. Management practices may have to be altered to combat this. For example, minimum tillage cultivation and/or stubble retention could be used to improve soil structure and organic content.

Figure 6 illustrates how an increase in the amount of rain would impose a form of Hicks biased technological change resulting in a shift towards chemicals (main input in low-till cultivation) at the expense of heavy machinery usage (main conventional cultivation input).

**Figure 6 - Impact of Increased Rainfall on Cultivation**



Heavier more intense rainfall could also affect the elasticity of substitution between these inputs. Cropping activities in north western NSW and southern Queensland are carried out on heavy black soils prone to compaction if worked in wet periods. Larger machinery may become relatively less suitable in this region due to increased compaction in generally wetter soil

## Table 3 - Effect of Increased Ambient Temperature: ORANI Classification

### (a) Pastoral, Wheat/Sheep and High Rainfall Industries

| Commodity | Pastoral | Wheat Sheep | High Rainfall |
|---|---|---|---|
| Wool | - small [c] | - medium [b] | - small [a] |
| Sheep | - small [c] | - medium [b] | - small [a] |
| Wheat | - 9% [dB] | - 9% [dB] | - 9% [dB] |
| Barley | - medium [h] | - medium [h] | - medium [h] |
| Other Cereals | - small [c] | -small [c] | - small [c] |
| Meat Cattle | - small [f] | - small [f] | - small [f] |
| Milk & Pigs | - medium [a] | - medium [a] | - medium [a] |
| Sugar/ | | | + 32% [eA] |
| Fruit | - 50% [bB] | - 50% [bB] | - 50% [bB] |
| VCOT | - small [g] | - small [g] | - small [g] |
| Poultry | - small [a] | - small [a] | - small [a] |

### (b) Other Agricultural Industries

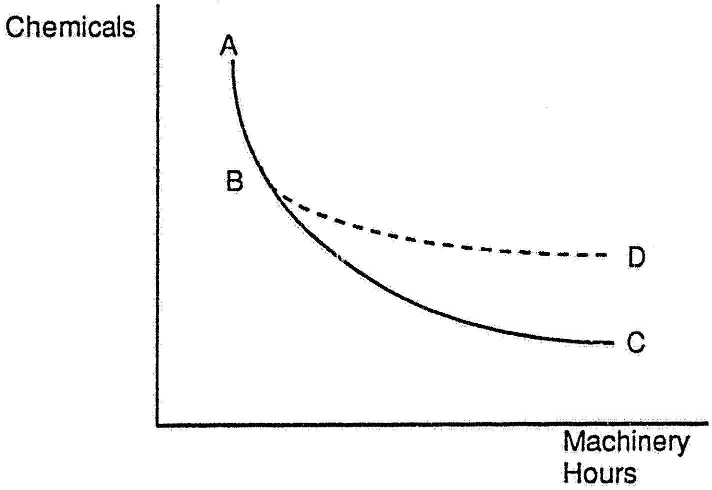
| Industry/Commodity | Impact on Production |
|---|---|
| Northern beef/ Meat cattle | - small [f] |
| Milk & pigs/ Milk cattle & pigs | - medium [a] |
| Sugar | + 32% [cA] |
| Fruit | - 50% [bB] |
| VCOT/VCOT | - small [g] |
| Poultry/poultry | - small [a] |

Authors

a - Lottkowitz (1989)
b - Pittock (1989)
c - Walker et al (1989)
d - Wang & Hennessy (1991)
e - Allen (1990)
f - McKeon (1988)
g - Ellis et al (1990)
h - Nulsen (1989)

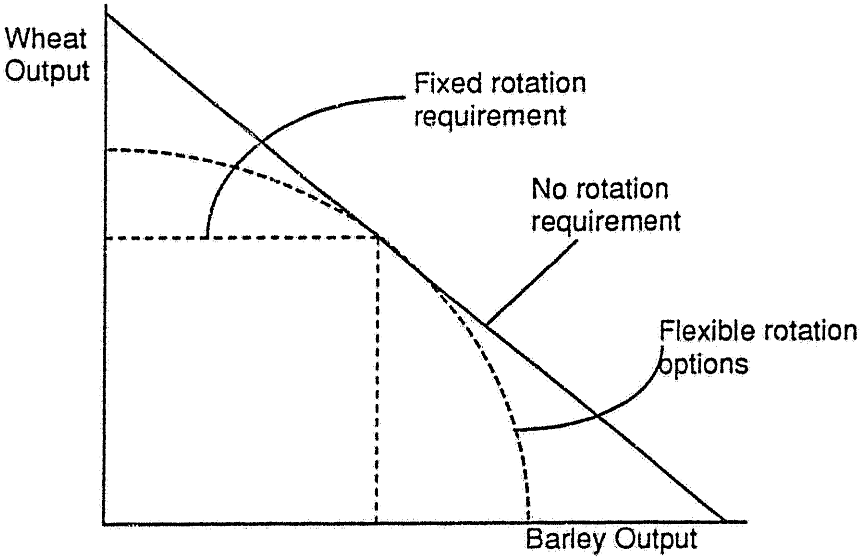
conditions, with the accompanying yield reductions. The responsiveness of changes in input mix may be reduced as opportunities decline for substituting machinery for chemicals. If the substitution possibilities could originally be represented by ABC in Figure 7 then, with higher more intense rainfall, the isoquant for the same level of production might become ABD.

**Figure 7 - Chemicals-Machinery Substitution**



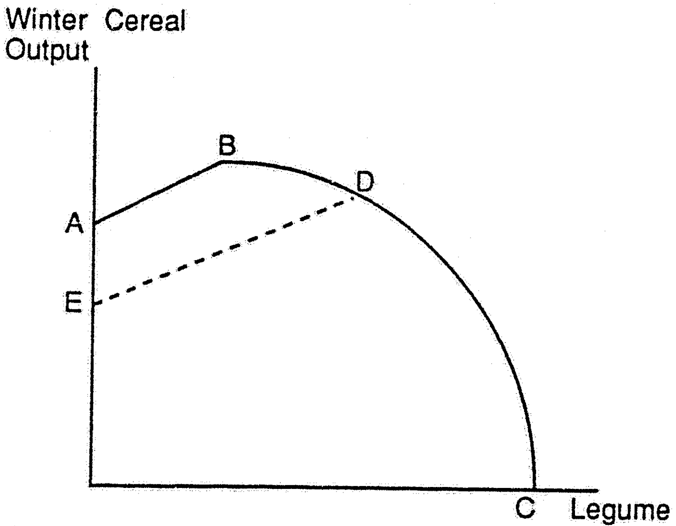
Increased rainfall and humidity could also increase the incidence of pathogens in crops grown as monoculture. Crop rotations may be required in order to break the disease cycle, thereby reducing the elasticity of substitution between the enterprises comprising the rotation. Figure 8 illustrates how the requirement for increasingly strict crop rotations reduces the responsiveness of, for example, wheat and barley output to changes in relative prices. Normally near perfect substitutes, stricter crop rotations would result in a situation where larger changes in relative prices would be required to induce changes in output mix. In the limit, with a single fixed rotation, relative output mix changes would not affect output levels.

**Figure 8 - Crop Rotation and Wheat-Barley Substitution**



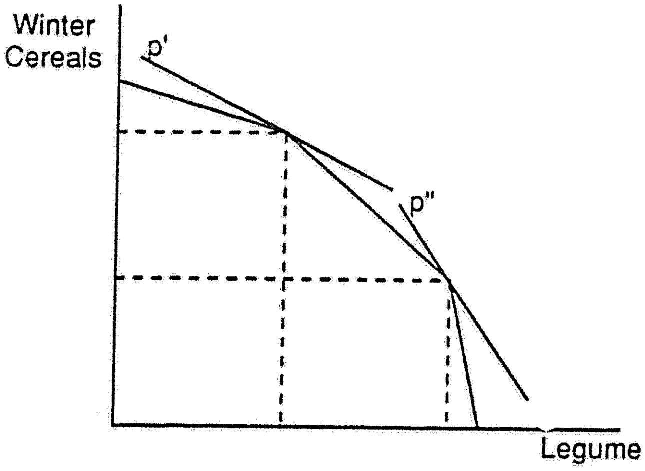
Winter cereal production could require legume rotations at closer intervals not only to help break the disease cycle, but also to assist in replacing soil organic matter and nitrogen lost through heavier rainfall. There may actually be a complementary relationship between winter cereals and legumes. With an EGE resulting in higher rainfall and consequent effects on soils and pathogens, the complementary relationship could intensify as output of cereals becomes more dependent on legume rotations. This is represented in Figure 9 by the shift in production possibilities from ABC to EDC, also reflecting the greater reliance of winter cereals on legume rotations (AB to ED).

**Figure 9 - Winter Cereal-Legume Substitution**



Crop rotations may become essential to the viability of some cereals in such a way that for small changes in output price, there would be no change in output mix. For large relative price changes, output mix would change discontinuously reflecting reduced output alternatives imposed by stricter crop rotations. This situation is illustrated by the piece-wise linear production frontier in Figure 10.

**Figure 10 - Piecewise Linear Production Frontiers**



## Table 4: Effect of Changes in Rainfall Patterns: ORANI Classifications

### (a) Pastoral, Wheat Sheep and High Rainfall Industries.

| Commodity | Pastoral | Wheat Sheep | High Rainfall |
|---|---|---|---|
| Wool | + small [a] | + medium [a] | + small [a] |
| Sheep | + 30-40% [c] | + 30-40% [c] | - small [a] |
| Wheat | + 35% [cB] | + 35% [cB] | + 35% [cB] |
| Barley | - small [b] | - small [b] | - small [b] |
| Other Cereals | + medium [a] | + small [b] | + small [c] |
| Meat Cattle | + small [c] | + small [c] | + small [c] |
| Milk & Pigs | - medium [d] | - medium [d] | - medium [a] |
| Sugar/ Fruit | + small [e] | + small [e] | + small [e] |
| VCOT | + medium [a] | + small [b] | + small [c] |
| Poultry | - | - | - |

### (b) Other Agricultural Industries

| Industry/Commodity | Impact on Production |
|---|---|
| Northern beef/<br>Meat cattle | + small [c] |
| Milk & pigs/<br>Milk cattle & pigs | - medium [d] |
| Sugar<br>Fruit | + small [e] |
| VCOT/VCOT | + medium [a] |
| Poultry/poultry | No effect |

Authors
a - Walker et al (1989)
b - Hobbs et al (1988)
c - McKeon (1988)
d - Lottkowitz (1989)
e - Pittock (1989)

(c) Available Data: As was the case for data relating to temperature change, the usefulness of any findings on the impact of changes in rainfall patterns on agricultural production will be limited by the accuracy of GCM predictions. Another important consideration is the difficulty involved with testing the yield and productivity response of crops and livestock to changes in rainfall regimes. Unlike changes in CO2 concentration and ambient temperature, the intensity, variability and seasonality of rainfall are not easily simulated in a controlled environment to facilitate the compilation of data.

As a result of the above mentioned factors, quantitative data relating to the impact of changes in rainfall patterns on agricultural production are very limited. Until further research is conducted in this area, including controlled and field experimentation, modelling of this impact will rely on best estimates. The most recent findings relating to the effects of changes in rainfall patterns are presented in Table 4.

## 4.4 Scourges

(a) Biology: Predicted higher winter temperatures and moister summer conditions will favour insect survival and population build-up leading to an intensification of vector spread diseases. The CSIRO Division of Entomology (1991) has identified three key aspects of the biology of pests, pathogens and disease most likely to be affected by climate change;

1) Shifts in geographic distribution - a wide range of pests and disease normally found in northern Australian regions will follow a general southward migration as ambient temperature and humidity increase.
2) Changes in epidemiology of diseases - changes in the endemic/epidemic nature of disease incidence in direct and vector borne diseases.
3) Changes in abundance - with particular emphasis on increases in development rates resulting in more generations per year in a warmer climate, changes in phenology and life cycles in response to changes in temperature daylength linkages, changes in survival/fecundity in response to moisture and temperature, changes in wind patterns affecting areas at risk from migratory insects and changes in "event driven" pest outbreaks (locusts, etc.) in response to changes in frequency and intensity of drought and rainfall.

(b) Impact on Production: Climate change is expected to extend the current areas affected by invertebrate pests and insect-vectored disease. The geographic distribution and population densities of many of the most serious parasites including cattle tick, sheep blowfly, buffalo fly, the bluetongue midge vector and barber's pole sheep worm will increase substantially (Sutherst and Maywald, 1990). One important example for the beef and dairy industries is the cattle tick. Current areas affected by this pest are forecast to extend from the existing boundary in northern NSW into the southern coastal regions of NSW and Victoria.

Bos indicus cattle will become more competitive with existing British breeds due to their greater tolerance of cattle tick infestation. Cattle tick causes losses in production and deaths amongst livestock introduced from tick free areas and would therefore impose biased technological regress against traditional British breeds of cattle. Elasticity of substitution between breeds should increase as southern beef producers begin to experience the costs and disruptions to production process currently imposed on northern beef producers.

Similar impacts will be imposed on sheep and wool production. The sheep blowfly is attracted to damp or rotting fleece caused by persistent rainfall, or humid conditions associated with scouring. Increases in the amount of summer rainfall and humidity would provide more suitable hosts, leading to an increase in the incidence of fly strike and a reduction in industry output through sheep losses and downgrading of fleece quality.

Another important consideration is the impact that pests and diseases would have on export produce which currently rely on freedom from infestation to maintain market share. In particular, live sheep exports would be affected if bluetongue virus spread into southern States, and stonefruits would be denied access to Japanese markets if Queensland fruit fly became established (Sutherst, 1990).

(c) Available Data: All research carried out on the potential for geographic shifts in the prevalence of invertebrate pests and insect vectored disease in response to climate change is highly speculative in nature due to the uncertainty associated with regional climate prediction. With this in mind, Table 5 outlines the probable impacts of the major pests and diseases on production as their geographic distribution alters in response to climate change.

## 5. Conclusion

Complete analysis of possible responses to the projected enhanced greenhouse effect requires systematic modelling of the potential effect of an EGE on the natural and social environments. In the case of Australian agricultural sector, this modelling requires examination of the agricultural sector with the rest of the economy together with indirect effects on agriculture of direct effects of an EGE elsewhere in the economy.

Direct effects of an EGE on the Australian agricultural systems were considered in this paper. These effects were analysed using ORANI's characterisation of Australian agriculture, as it is proposed to examine potential EGE effects on Australian agriculture using ORANI. The potential direct effects of an EGE were summarised as CO2 fertilisation effects, temperature effects, rainfall effects and scourges (pests, diseases and weeds). There are reasonably good estimates of the CO2 fertilisation effect on agricultural productivity, although there are some doubts as to how these estimates will translate into observed field effects. Less detailed estimates are available for temperature and rainfall effects and estimates for scourges appear to have low reliability. These estimates permit the representation of some aspects of changed production technology resulting from an EGE. Some aspects of changes in input and output mix may be modelled in ORANI from their production technology changes. It has not yet proved possible, however, to model the direct effects of potential EGE changes on natural resources such as land; nor, particularly, changes in input and output substitution elasticities that might arise from an EGE.

## Table 5: Effect of Increased Invertebrate Pests and Disease: ORANI Classifications

### (a) Pastoral Wheat/Sheep and High Rainfall Industries.

| **Commodity** | **Pastoral** | **Wheat Sheep** | **High Rainfall** |
|---|---|---|---|
| Wool | - large [b] | - large [b] | - large [b] |
| Sheep | - large [b] | - large [b] | - large [b] |
| Wheat | - small [b] | - small [b] | - medium [b] |
| Barley | - small [b] | - small [b] | - medium [b] |
| Other Cereals | - small [e] | - small [e] | - medium [e] |
| Meat Cattle | - medium [c] | - medium [c] | - medium [c] |
| Milk & Pigs | - large [d] | - medium [c] | - large [d] |
| Sugar/ Fruit | - large [d] | - medium [c] | - large [de] |
| V.C.O.T. | - medium [e] | - medium [e] | - medium [e] |
| Poultry | - | - | - |

### (b) Other Agricultural Industries

| **Industry/Commodity** | **Impact on Production** |
|---|---|
| Northern beef/ Meat cattle | - medium [c] |
| Milk & pigs/ Milk cattle & pigs | - large [d] |
| Sugar Fruit | - large [d] |
| VCOT/VCOT | - medium [e] |
| Poultry/poultry | No effect |

<u>Authors</u>

a - NSW Dept. Agriculture (1989)
b - Sutherst (1990)
c - Sutherst and Maywald (1990)
d - Lottkowitz (1989)
e - McKeon (1988)

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