Centre for Agricultural Strategy

# The 'greenhouse effect' and UK agriculture

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# 4 The 'greenhouse effect' and animal production in the UK

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## INTRODUCTION

Most of the definitive research work on the 'greenhouse effect' has been done on plant growth and little on the specifics of livestock production. Much of this paper, therefore, must perforce be speculative and based upon numerous assumptions, few of which have been subjected to experimental challenge.

## ASSUMPTIONS AS TO CLIMATIC CHANGE

Most models of future climate change take the forcing term to be a doubling of pre-Industrial Revolution levels of carbon dioxide to 540 ppm by the year 2050. Most models predict, for the UK as a whole, that mean temperatures will rise by 3°C with an uncertainty (ie variation between models) of ±1.5°C. This rise in temperature is seasonally dependant, with winter temperatures being about 4°C, and summer temperatures about 2°C, higher.

The effect on rainfall, and humidity, is much less clear-cut. The various models differ in predicting changes in precipitation but most agree that there will be a change of the order of ±20% according to season and according to region.

In general, the changes in mean temperature will be similar in effect to an apparent southward shift in latitude of about 10°. Thus, north-east Scotland will have a similar mean annual temperature to that of present day south-west England, while the climate of the southern UK will come closer to that of south-west France. More uncertainty surrounds the regional variation in precipitation, with most models agreeing that the western parts of the UK will retain their maritime influence, but that central, eastern and southern England will probably shift to a more semi-Mediterranean climate with drier conditions. Further north, northern England and Scotland will be warmer but not necessarily drier, and it is in these regions that the rainfall effects are most difficult to predict.

Changes to upland climates will be important as such regions are of great significance to ruminant livestock production patterns in the UK. The lapse rate of mean temperature adopted by the UK Meteorological Office is 6°C per km (Taylor, 1976), varying by about ±2°C per km, depending on air mass type, slope and aspect. Thus an average rise of 3°C by the year 2050 is equivalent to an effective reduction in altitude of about 500 m with consequences for the number of growing degree-days. However, due to the uncertainty regarding precipitation, the actual effect on total growing days could well be severely limited if significant areas of the UK experience hotter and drier summers with increased drought periods when plant growth is minimal or non-existent.

Because of the different water-holding capacities of soil types, the climatic changes summarised above will be greatly modified by soil and subsoil. Heavy clays and light sands will be most affected by significant shifts in precipitation, whilst more balanced deep loams will be less affected.

## EFFECTS ON CROPS FOR LIVESTOCK FEED

Climatic change will affect the production of feed crops in several ways. These are:

(i) the area of the particular crops grown;
(ii) the yield of these crops;
(iii) the timing of production with respect to livestock requirements;
(iv) the efficiency of harvest and storage;
(v) product quality;
(vi) cost of animal feed production.

Some of the main factors are considered below.

Whether or not a crop can be grown in the UK depends primarily on whether there is a sufficiently long growing season, which is itself influenced firstly by temperature and secondly by the availability (or excess) of water. As weather changes from year to year it is less important to find out whether the crop will grow in an average year, but more important to assess the probability of success over a number of years. Possibly, failure in one year out of ten might be an appropriate acceptable level of risk.

A model has been constructed which estimates the potential increase in area for particular food crops (Russell, G, personal communication). The proportion of the UK for different feed crop uses was estimated on the basis of rules drawn up for success as shown in Table 1. Five scenarios were examined:

(i) present climate;
(ii) a temperature rise of 4°C in winter and 2°C in summer, no change in the after balance;
(iii) temperature as in (ii), rainfall +20%;
(iv) temperature as in (ii), rainfall and potential transpiration +20%;
(v) temperature as in (ii), rainfall −20%.

The proportion of the UK for different land uses was then estimated by applying rules drawn up for the success of various enterprises (Table 1) to a database of information on soils and climate (Blackman *et al*, 1963; Francis, 1981; Smith, 1984) compiled for 115 random locations in the UK.

Table 1
**Rules of success**

Arable if $H_0>2750$ and soil 2 or 4 and $(R-PE)<500$.

Silage maize *if* arable *and* $H_{10}>900$.

Grain maize *if* arable *and* $H_{10}>1000$.

Sunflower *if* arable *and* $H_{10}>1000$.

Soya *if* arable *and* $H_{10}>1215$.

Permanent grass if $H_0>2400$ and soil 1 or 2 or 4 and not arable.

Forest if $H_0>1859$ and soil 1 or 2 or 4 and not arable or permanent grass.

Rough grazing *if not* arable *or* permanent grass *or* forest.

Urban and other non-rural areas occupy 6% of the total.

Forest occupies 3% of the arable and permanent grass areas and 5% of the rough grazings.

Forest and urban areas remain constant.

Maize can be grown one year in four, sunflower and soya one in six.

Where H is the annual accumulated temperature above the subscripted base temperature; soil 1 = hill peat, 2 = mineral soil derived from glacial drift and 4 = *in situ* soil; (R−PE) is the balance between precipitation and potential evaporation.

The predicted current areas were compared with the agricultural statistics (Central Statistical Office, 1988; Eurostat, 1988) and future areas were predicted (Table 2).

Table 2

**Actual v predicted land use pattern**

The area of land classes (x$10^3$ha) currently (1987) and for five climatic change scenarios.

| | | *Scenario* | | | | |
|---|---|---|---|---|---|---|
| Land Class | 1987 | (i) | (ii) | (iii) | (iv) | (v) |
| Arable | 7.0 | 7.7 | 7.7 | 5.8 | 6.9 | 9.0 |
| Permanent grass | 5.1 | 6.5 | 6.9 | 8.8 | 7.8 | 5.7 |
| Forest | 2.6 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 |
| Rough grazing | 7.8 | 6.0 | 5.5 | 5.5 | 5.5 | 5.5 |
| Urban | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 |

The area of four arable crops (x$10^3$ha), curently and under five different climatic scenarios.

| | | *Scenario* | | | | |
|---|---|---|---|---|---|---|
| Crop | 1987 | (i) | (ii) | (iii) | (iv) | (v) |
| Silage maize | 10 | 300 | 40 | 40 | 40 | 170 |
| Grain maize | 0 | 300 | 1670 | 1330 | 1550 | 1760 |
| Sunflower | 0 | 200 | 1110 | 890 | 1030 | 1170 |
| Soya | 0 | 0 | 770 | 640 | 700 | 820 |

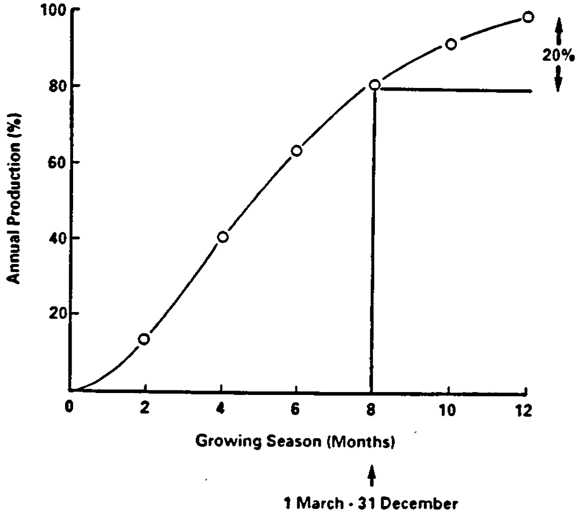
Table 2 shows that there are significant differences between the actual and the predicted current areas. Some land that is suitable for arable crops of livestock feeding significance is currently under permanent pastures and rough grazing. Thus biological and ecological considerations indicate that total cropping areas, including feed crop areas, are capable of expansion, and this expansion is likely to be even greater with the predicted climatic changes over the next half century. Thus the limitations to feed crop production in the UK are likely to be economic, political and sociological, rather than biological, ecological or climatic.

Considering the simplified nature of the rules, the agreement between the actual and predicted areas is good. Comparing the four future scenarios with the one for the present, the main result is that the arable area seems to be insensitive to temperature change but to depend closely on the water regime. This is in accord with experience, since arable areas are often differentiated from non-arable because of rainfall or soil rather than temperature. Clearly the rainfall regime, which is difficult to predict, will play a key role. The effect of rain will depend on its seasonality as well as the total amount, and it is possible to imagine cases where the annual rainfall rises but the summer rains decline. The effects of seasonality of rainfall have not been included in the calculations.

Of particular relevance to ruminant livestock production is the productivity of the grass crop. This crop is unique in that it is cropped continuously throughout the year albeit with major seasonal fluctuations. It is therefore tempting to suggest that higher soil and ambient temperatures would increase the growing season and hence increase the total biomass production throughout the year as a whole.

Figure 1

**The effect of growing season length on annual production of a grass sward**



*Assumptions*

i) Production ($t.DM.ha^{1}$) = $\Sigma \int_{t = t_1}^{t = t_2} f.Qdt$ Growing season = $t_2 - t_1$; Q = solar radiation.

ii) Σ, the dry matter radiation quotient, is unaffected by temperature and plant age.

iii) 90% of the incident radiation is absorbed by the canopy (f) except in the first and last month of growth when the proportion falls to 0.50.

iv) the growing season is symmetrical about July 31.

v) Broom Barn (Suffolk) is a representative meterological station.

However, such effects are not likely to be as large as might be expected, because of the limitation set by solar radiation receipts. Figure 1 indicates, from solar radiation data derived from Brooms Barn Experimental Station in Suffolk, the total theoretical annual production of grass according to the length of the growing season. Thus, over a 6-month growing season, about 70% of annual productivity is realised. From 6 to 8 months potential production only increases by 12% and from 8 to 10 months by a further 11%. The actual increase in growing season is likely to be much less than this – of the order of one extra month or so – and thus the increase in total annual grass production is likely to be much less than 10%. Moreover, if the rise in temperature is accompanied by an increase in cloudiness, and thus a reduction in solar radiation, then the beneficial effect of warmer temperatures could easily be cancelled out.

The timing of production is of particular importance in the grass crop where some systems may be limited by the onset of growth of grass in the spring. However, the key date is not actually the date when growth is first observed, but rather the date when the growth rate of the sward is sufficient to allow continued growth even under the pressure of grazing. If it is assumed that a grass sward absorbs 90% of the incident photosynthetically active radiation, that the dry matter: radiation quotient is 3 g/MJ (Russell *et al*, 1989), and that 10% of the production is partitioned to the roots, then the initial potential growth rate can be computed for swards starting growth at different times of year. A grass sward starting growth in mid-January could grow at a rate of 3 g/m$^2$/day, whereas one starting growth in mid-April would grow at 16 g/m$^2$/day. These are over-estimates since initial growth is likely to be depressed by low temperatures, shortage of nitrogen and incomplete leaf canopy. In addition, when conditions are unfavourable for photosynthesis, assimilate is translocated preferentially to the roots and stem base reserves, to the detriment of foliage growth (Gillet *et al*, 1984). Only foliage growth is relevant to the ruminant animal.

Extending the length of the growing season into the early spring could also pose managerial problems under certain circumstances. If the winters become warmer and wetter, turn-out of cattle onto heavier soils could be limited, not so much by grass growth as by the danger of poaching. If, however, the winters are both warmer and drier, early turn-out becomes much more feasible.

Another consideration with regard to grass growth is the length of the summer drought period. In the drier areas to the east of the UK, growth is limited by shortage of water in mid-summer. Whether or not this summer drought period will worsen or improve will depend entirely upon how annual precipitation patterns will differ from current mean levels. As already stated, changes in annual rainfall are difficult to predict, but hotter, wetter summers would favour increased grass production compared to hotter, drier summers, just as hotter, drier winters would favour early turn-out of in-wintered cattle.

The value of grass is dependent on its nutritional quality as well as its quantity. Nutritional quality is low in the spring when dry matter percentage is low, and also in the late autumn when crude fibre levels are high. It therefore follows that an extension of the growing season into early spring and late autumn will continue to result in the production of extra grass of lower than average quality at both ends of the season. The quality of mid-seasonal grass will depend upon the growing conditions at that time.

To summarise, the effect of higher temperatures is likely to produce less than 10% extra total grass yield, and this extra grass, produced early and late in the season, will be of relatively lower nutritional quality.

## DIRECT EFFECTS OF AN INCREASE IN CLIMATIC TEMPERATURE ON LIVESTOCK

An animal responds to the temperature of its environment, which is a consequence of the climatic temperature and the amount by which this is modified by the shelter or housing provided. An increase in climatic temperature may, or may not, increase the temperature experienced by the animal. Where it does lead to an increase there may, or may not, be an effect on animal performance. The factors affecting whether these effects occur or not may be summarised as below.

### The effects of temperature on livestock

In the long-term, heat losses must equal heat production. Over a restricted range of temperature, heat loss can be maintained constant but this range may be very narrow (as in the case of day-old chicks) or very wide (as in the case of long-wool sheep). At temperatures below the lower end of this range, known as the lower critical temperature (LCT), heat loss must increase as temperature falls further. At temperatures above the upper end of this range – the upper critical temperature (UCT) – heat loss is insufficient to prevent the temperature of the animal (TA) from rising.

Within limits between LCT and UCT, the animals are in their so-called 'comfort zone' and within this zone biological efficiency is at its maximum. Above the upper limit of the comfort zone, but below UCT, the appetite of the animal will be reduced and feed conversion efficiency will be lower. Reproductive efficiency, especially of the male, will also be impaired.

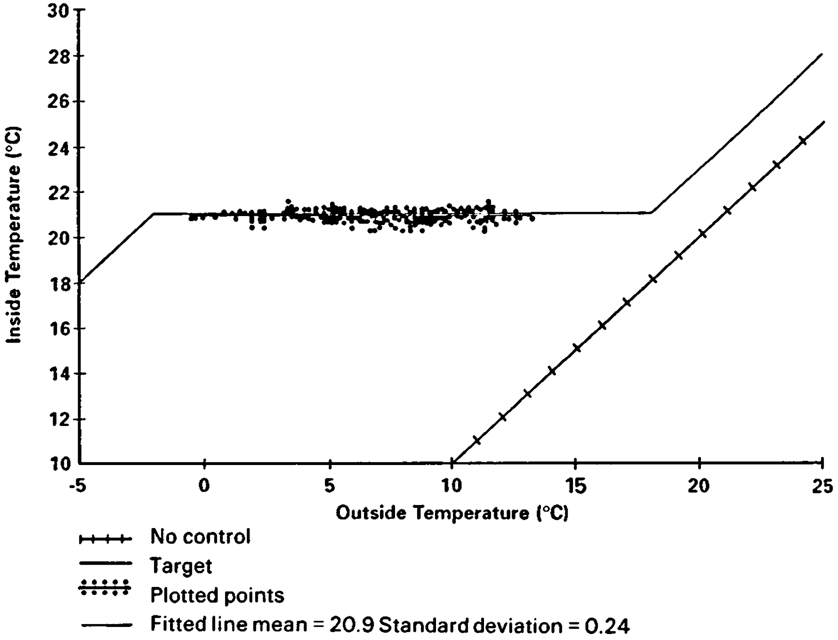
If an increase in temperature causes the temperature to be above the UCT, feed intake and performance will both fall, efficiency will decrease markedly and reproductive efficiency will be severely impaired.

### The relationship between climatic temperature ($T_C$) and the temperature that the animal experiences ($T_A$)

The aim is to keep the $T_A$ above the LCT and lower than the UCT. In housed animals this is done by insulating the structure, having a high stocking rate and by varying the ventilation rate. This strategy can be very successful as shown in the data presented in Figure 2.

Where $T_C$ is such that $T_A$ is less than LCT (as with young chicks and piglets in the UK in winter) heat must be used to bring $T_A$ up to the LCT. Where $T_A$ is greater than UCT then expensive cooling techniques could be used to reduce $T_A$ below UCT. The energetic cost of such techniques is very dependent on relative humidity.

Figure 2
**Environment evaluation**
**Regression: Mean inside against outside temperature**



Source: Derived from Charles (1989).

In summary, therefore, an increase in the climatic temperature will on the one hand reduce the need for energy in heating pig and poultry houses in the winter, and increase the need to cool such houses in the summer. It is probable that the heating energy saved in winter will exceed the extra energy expended on cooling during the summer and hence an increase of 3°C in mean climatic temperature will tend to increase the overall energetic efficiency of monogastric production.

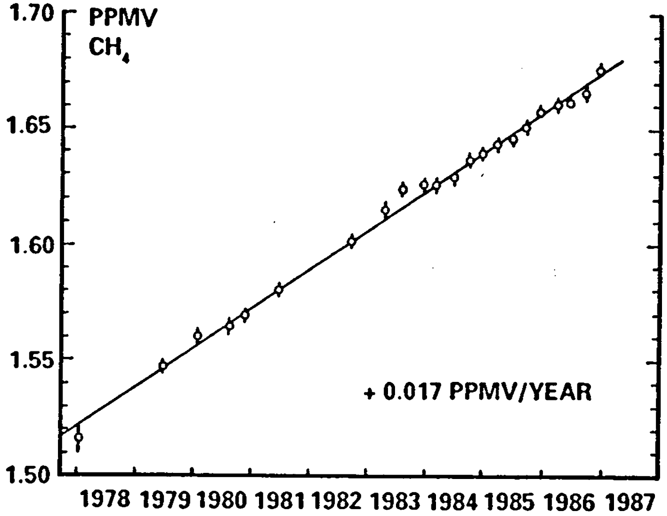
It would be possible to model all these effects for different classes of livestock against different climatic scenarios, but it is not likely that the refinements thus produced would vary these broad generalisations. Again, the most major differences in energy usage will be between seasons rather than between the past and future mean climatic values.

## EFFECT OF LIVESTOCK POPULATION ON GLOBAL METHANE BUDGETS

The current atmospheric concentration of methane is about 1.7 ppmv (Figure 3) and has increased by about 2% per annum on average for the last century. Previous to 1900, methane concentrations were fairly static (see Figure 4).

The ambient temperature would be calculated to increase by about 1°C with a doubling of the current methane concentration, assuming only the direct radiative effects of methane. The atmospheric residence time of methane is about 10 years and is thus very long relative to the reactive trace gases in the atmosphere (ozone residence time is 0.01 year).

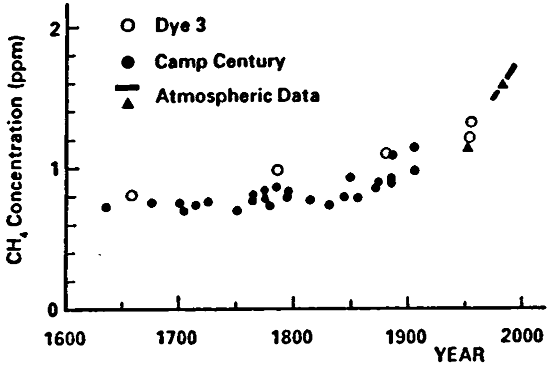
Figure 3
**Global average tropospheric methane concentration**



Source: Derived from Blake & Rowland (1987).

Figure 4

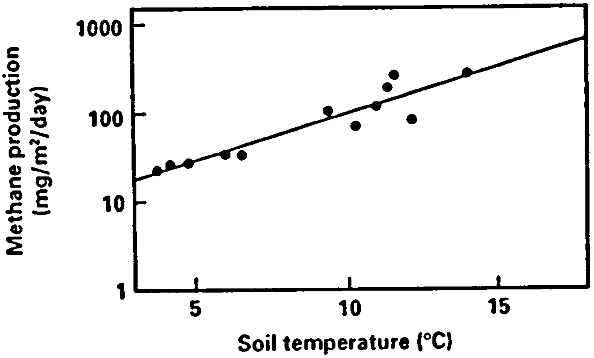
**Changes in the atmospheric concentration of $CH_4$ estimated from ice core data**



Ice core data are from Craig & Chou (1982) and Rasmussen & Khalil (1984). Atmospheric data are from Blake & Rowland (1987) and Rinsland *et al* (1985).

Figure 5

**The effect of soil temperature on methane production in fen lands (Minnesota data)**

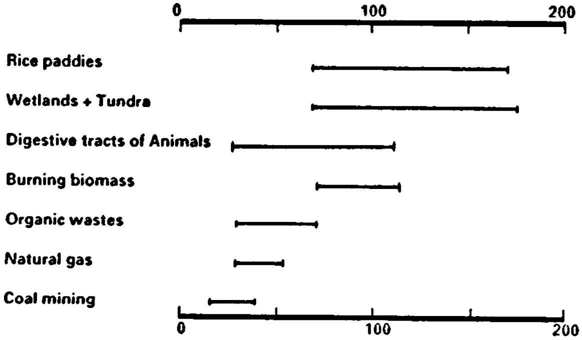


The sources of methane include rice paddies, wetland and tundra. As soil temperature rises so also does the production of methane from these soil types, as shown in Figure 5.

The total input of methane to the atmosphere lies in the range of 300–550 Mt per year. The methane is derived from seven main sources as shown in Figure 6.

It will be seen from Figure 6 that the two dominant sources of methane production are the anaerobic fermentation of organic matter by bacteria in rice paddies, wetlands and tundra, as already discussed. Methane production from the digestive tracts of animals ranks in third place, and

Figure 6
**Global emissions of methane (Mt/year)**



results in a flux to the atmosphere of about 85 Mt per year. This contribution to atmospheric methane has been re-calculated from first principles, using the knowledge that methane output varies markedly between species, is linked to the energy maintenance requirement (expressed as ME) and also to the body size.

Assuming that energy required for animal maintenance is 0.4 MJ of ME/kg$^{0.75}$ per day, then the various methane production rates of different classes of farm animal can be tabulated as shown in Table 3. The data are provided on a global basis since the effect of methane production on climate is not localised.

Table 3
**Methane production by livestock**

| Livestock Class | $CH_4$ production (as % of ME) | Mean wt (kg) | 1987 World population (M) |
|---|---|---|---|
| Cattle + Buffalo | 8 | 400 | 1420 |
| Sheep + Goats | 8 | 40 | 1660 |
| Camels | 6 | 500 | 19 |
| Horses | 3 | 450 | 66 |
| Other equines | 3 | 275 | 56 |
| Pigs | 1.5 | 60 | 840 |

Using this data, the daily methane production of the World's livestock population is equivalent to approximately $6 \times 10^9$ MJ of ME per day, of which about three-quarters is derived from cattle and buffalo. By contrast, the methane production by the World's human population (some 5 billion) is approximately 0.4 x $10^9$ MJ of methane per day.

Expressed another way, the total gross energy equivalence of the methane gas produced by the World's livestock population approximates to about 116 Mt of barley per year or 66 Mt of coal a year, or 146 Mt of wood per year (using energy equivalence of 33.5 MJ of GE/kg for coal and 15 MJ of GE/kg for wood).

## OTHER LIVESTOCK CONSIDERATIONS

As stated in the introduction, this section will mainly pose questions and suggest possible answers. Key issues are dealt with for which no definitive data are available and consequently the comments made are subjective.

### Possible change in the UK livestock population

Climatic considerations are unlikely to be the main factor causing changes in the UK livestock population. Socio-economic and politico-economic considerations are likely to be of much greater importance. Thus, the effect of 1992 on lowering the trading barriers within the EC and the construction of the Channel Tunnel, are more likely to affect the pattern of home production versus importation of livestock products rather than a mere 3°C shift in mean climatic temperatures. Also, any significant shift towards a more vegetarian style of diet, for purely subjective reasons, is likely to be as important a factor in influencing the UK livestock population as a shift towards slightly longer summers and shorter winters.

### Possible effect of climatic change on livestock productivity

As has been indicated in an earlier section, livestock have relatively wide 'comfort zones', and providing monogastric animals are warmed in winter and cooled in hot summers there is no reason to believe that the average livestock performance, in terms of biological energetic efficiency, will alter as a result of a 3°C change in mean ambient temperatures. Indeed, changes due to improvements in biological efficiency through breeding, particularly in view of the dramatic improvements likely to occur as a result of new developments in biotechnology, are likely to be of much greater importance in increasing livestock productivity.

### Effects of climate on livestock diseases

There are likely to be some effects of climate on both endo- and ecto-parasites but, once again, seasonal differences in climate, and between-year variation in climate, are likely to be as significant as the longer-term cumulative effects of climatic change. It is likely that warmer summers will favour certain ecto-parasites, especially ticks. An increase in the number of tick species as well as in the total tick population, could result in the UK being subjected to certain tick-borne diseases currently regarded as 'exotic'.

Bacterial and viral infections of farm animals are also influenced by environmental conditions, but the differences between, for instance, housed cattle and out-wintered cattle and housed sheep and out-wintered sheep are likely to have a greater effect on disease prevalence then a small shift in mean ambient temperature.

Finally, any relaxation of the currently strict quarantine arrangements for animal importations into the UK is likely to have a very much greater effect on the future disease pattern of the UK livestock population than any relatively small change in climatic conditions.

In short, there will be changes in the range and type of diseases affecting farm livestock, but many of these changes are likely to occur as a result of modifying factors entirely distinct from climatic change as such.

## CONCLUSION

On balance, a rise of 3°C in mean climatic temperature will be favourable to livestock production both directly, in terms of less energy inputs, and indirectly, in terms of better range and yield of feed and fodder crops.

However, agriculture, as an industry, is a contributor to the global warming process. The livestock population increases global warming through increasing atmospheric methane, and the livestock support industries contribute in a manner similar to non-agricultural industries.

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## REFERENCES

Blackman, G E *et al* (1963) *The atlas of Britain and Northern Ireland.* Oxford: Clarendon Press.

Central Statistical Office (1988) *Monthly digest of statistics No 504.*

Eurostat (1988) *Agricultural Statistics Yearbook.* Theme 5 Series A. Brussels: Eurostat.

Francis, P E (1981) *The Climate of the agricultural areas of Scotland.* Climatological memorandum No 108. Bracknell: Meteorological Office.

Gillet, M, Lemaire, G & Gosse, G (1984) Essai d'elaboration d'un schema global de la croissance des graminees fourrageres. *Agronomie*, **4**, 75–82.

Russell, G, Jarvis, P J & Monteith, J L (1989) Absorption of radiation by canopies and stand growth. In: Russell, G, Marshall, B & Jarvis, P G (Eds) *Plant Canopies: their Growth, Form and Function.* Cambridge: CUP.

Smith, L P (1984) *The agricultural climate of England and Wales.* MAFF/ADAS Technical Bulletin 35. London: HMSO.

Taylor, J A (1976) Upland climates In: Chandler, T J & Gregory, S (Eds) *The Climate of the British Isles.* London: Longman.