Future of Irish Agriculture - Role of Climate

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J. F. Collins (Editor)

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Agriculture will always be a 'core activity' of the Irish economy as well as being an important component of the social fabric of the country. Our preoccupation with weather reflects the central importance the Irish Climate plays in this regard. New challenges face the industry : reform of CAP, GATT agreements, quality of agriculture produce, impact of agricultural activities on the environment and negative impacts of industry on agriculture.

There are legitimate concerns about climate change, climate variability and the effects these have on changing production patterns such as the introduction of new crops and unfamiliar diseases of crops and animals. Concern for the atmosphere, land use and ecosystems will have an impact on agricultural management. For agriculturists who are increasingly conscious of the results of their actions on the environment, and who still must run a profitable enterprise, a better understanding of climate variability and climate change would be reassuring. In short, the agricultural industry of the future will seek efficiency in food production but with concern for, and in harmony with, both the atmosphere and terrestrial environments.

A number of well-known scientists were brought together on February 27/28 1992 to assess climate change prospects and the perceived consequences for Irish agriculture. Their submissions also dealt with the likely constraints placed on agricultural practices and with suggestions as to how conflicting demands or requirements can be harmonised and accommodated.

The Conference Proceedings should appeal to a wide readership : farmer organisations and individual farmers, foresters, veterinary officers, agricultural researchers and advisors, university personnel, environmentalists, engineers, county managers, and those generally interested in and climate change.

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THE GREENHOUSE EFFECT AND AGRICULTURE IN N.W. EUROPE

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INTRODUCTION

There is a growing indication that increasing amounts of carbon dioxide (CO_2) and other greenhouse gases such as methane and nitrous oxide in the atmosphere will lead to an increase in the average surface temperature of the Earth. The estimated range of increase is 1.4°C to 2.9°C above pre-industrialised levels by the year 2030. This is equivalent to a rise of 1.1°C above present-day temperatures (IPCC, 1990).

At the level of northwest Europe only the most generalised changes can reasonably be estimated, and even these are unclear. In the absence of more precise information it may be reasonable, for the present, to assume that changes in average annual temperatures in northwest Europe will broadly follow those best estimates of changes in global average temperatures estimated under the "business as usual" scenario. This suggests an increase of about 0.5°C by 2000-2010, about 1.5°C by 2020-2050 and about 3°C by 2050-2100+, with warming in northwest Europe possibly more pronounced in winter than summer. These estimates have been made by the Climatic Research Unit at the University of East Anglia (Wigley, 1989). The ranges in the timing of temperature increases given here reflect uncertainties about how the climate will actually respond.

Possible changes in rainfall in the UK are much less clear. In the south and east there may be less summer rainfall and more winter rainfall ; while in the north and west both winter and summer rainfall could increase (DOE, 1988). There is a possibility that, with higher temperatures, we may receive more of our rainfall in the form of convective thunderstorms than we do at present.

Though we should not be complacent, particularly with the high degree of remaining uncertainty, the implications of these climatic changes for northwest Europe do not seem as dramatic as some other parts of the world and are in many respects ones that offer opportunities to UK agriculture. This paper outlines both the potential opportunities and costs that the future may hold.

The potential effects of climatic changes

It is useful to distinguish between two broad types of effect on farming : the fertilising effect that increased atmospheric CO_2 may have on plant growth, and the effect of changes in weather on crops, livestock, diseases, pests, weeds and soils.

The fertilising effect of increased CO_2

Carbon dioxide in the atmosphere can enhance plant growth in a number of ways : it can increase the rate of photosynthesis, leading to greater leaf expansion and a larger canopy. This is why hothouse growers frequently raise CO_2 levels artificially. In addition higher CO_2 concentrations can reduce water losses from crop plants - a beneficial effect where drought is a problem.

The effects are much more pronounced, however, in some crops than others. C3 crops (such as wheat, barley, rice and potatoes) respond vigorously to CO_2 enhancement. But C4 crops (such as maize, sorghum and sugar cane) do not. Crops in central and northern Europe thus stand to gain, although the outlook is not so good in much of Africa where maize, sorghum, sugar cane and millet are staple crops.

In addition, it should be noted that in north-west Europe the more troublesome weeds for arable farming (which compete with a growing crop for light, nutrients and moisture) are all C3 species and should benefit from $C0_2$ enhancement. Although little experimental evidence is available, it is likely that they could become more troublesome if C4 crops such as maize are cultivated widely. The most noxious C4 weeds, which are currently found in warm dry regions such as the Mediterranean, would probably benefit less from CO_2 enrichment, although it is questionable whether the postulated changes in climate in Britain (at least over the next 50 years) would provide a suitable environment for their colonisation here.

More research is needed before we can say how much yield increase will occur in crops, but for a doubling of CO_2 it could be as much as 40% for wheat and barley (Cure 1985). However, even under the "business as usual scenario" this would not occur until the 21st century. We should roughly halve this figure for effects that might occur by about 2030 (because increases in CO_2 account for only about half of the greenhouse gas forcing). And there are some negative aspects : the food quality of plants tends to deteriorate as carbon dioxide levels increase. Leaves become richer in carbon and poorer in nitrogen. Pests feeding off these leaves may thus need to consume more to gain their required nitrogen nutrient levels (Oechel and Strain, 1985). Moreover, if plants grew more quickly they would need more fertiliser. And if rainfall increased while plants required less moisture, might that mean more run-off, more erosion of the soil and more leaching out of soil nutrients ?

Effects of changes in weather

The effects through changes of climate and weather are less easy to determine because they will continue to vary greatly from year to year and from region to region; and since we have difficulty enough forecasting the weather beyond two or three days, we are far from able to predict climate over two or three decades. Because of this, we must restrict our predictions to ones of average (equilibrium) conditions that might prevail under an increase in greenhouse gases equivalent to a doubling of atmospheric CO_2 and assume that the trend of change towards that condition is roughly linear.

Let us consider first the changes in potential for farming. The growing period could lengthen in northern Europe if average temperatures increased. Under a climate predicted by one model for an equivalent doubling of CO_2, the number of months with average temperatures about 5^oC and rainfall exceeding half of potential evapotranspiration would exceed 9 throughout northwest Europe save for the extreme southeast where the growing season in the future might be interrupted by moisture shortage during the summer. Yet in the Mediterranean the growing season could shorten significantly due to warmer and drier conditions in spring and autumn. Seen in these simple terms, there is a shift of cropping potential from southern EC countries to northern EC countries.

Higher temperatures also imply that crops which are at present near their northern limit of cold tolerance in northwest Europe would benefit, providing moisture remained in sufficient supply. Thus the temperature limit for the successful ripening of grain maize, which at present lies in the extreme south of England, would be re-located across central England and Ireland with an average warming of 0.5 degrees C, across northern England for + 1.5 degrees and across northern Scotland for + 3 degrees (Figure 1a). This is an average location for an average warmer climate, and is based on temperatures adjusted to sea level. Year-to year variations could still be expected to occur around this average, just as they do now. For example, the temperature limit for maize in the summer of 1976 lay well north of its present normal position.

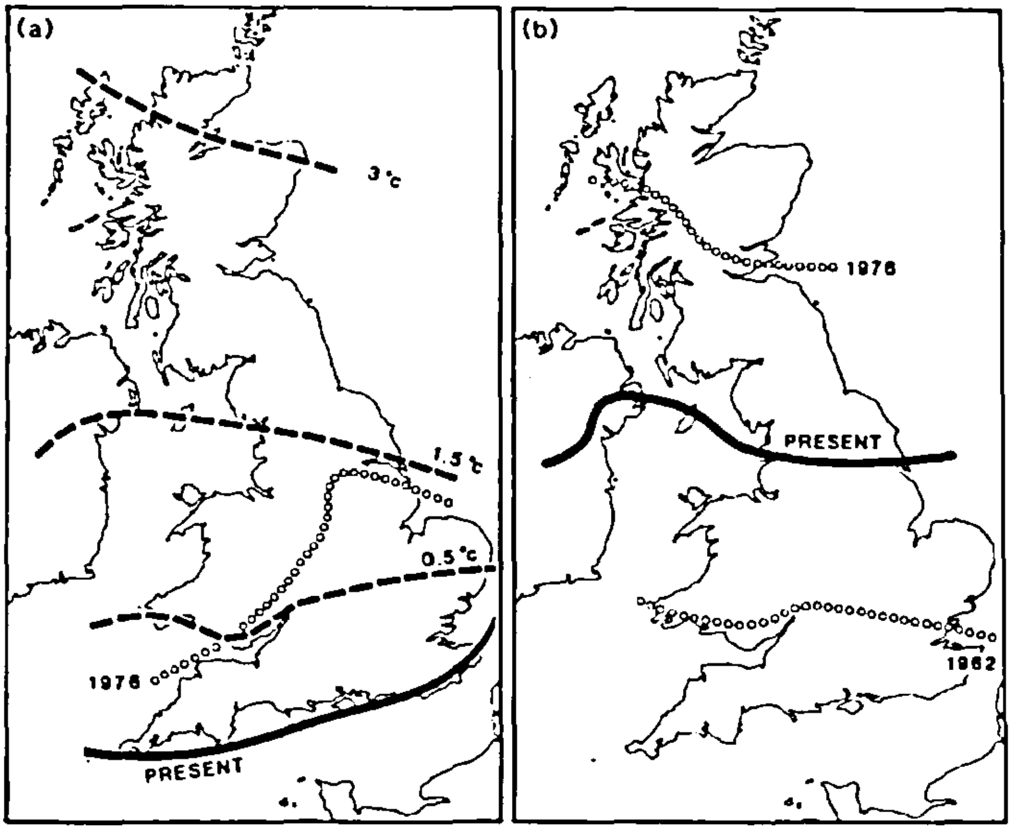

Figure 1 Hypothetical limits for successful ripening of two crops based on temperature : (a) Grain maize (requirement : 850 degree-days above a base temperature of 10 degrees C), and (b) Silage maize (requirement : 1460 degree-days above a base temperature of 6 degrees C). Mean limits (think solid lines) are representative of lowland conditions, based on temperature data from 78 stations for the period 1951-1980. Also shown are limits for individual years (open circles) and limits for arbitrary adjustments in mean temperature (broken lines). For further explanation, see text.

The corresponding limit for silage maize can also be mapped according to its temperature requirements (Fig 1b). These are less demanding than those for grain maize, thus defining a present-day boundary across the (cooler) north of England and Ireland. Again the year-to year variations around this average can be quite significant, illustrated here by the contrast between a warm year (1976) and a cool year (1962). Indeed, the scale of shift of such limits from the warmest to the coolest years in the past 30 years, is broadly similar to that expected to occur under a 2 to 3 degree warming. Any future warmer climate would also have embedded within it the year-to-year variations of growing season that we experience now, but whether the range of these variations will be similar to the range experienced today is uncertain. This temperature limitation is, of course, only one of several limitations placed on maize growing in north west Europe. The pattern of rainfall is also likely to change ; and while temperature and rainfall may alter, daylength (which is also important) will not.

Several crops are constrained in northern Europe as much by lack of sunshine and by quite high levels of air humidity as by temperature. Sunflowers, for example, are restricted at present to the extreme south of England, and even here there is a problem of mildew before the seedhead is fully ripe. But whatever remain the other constraints on sunflower growth, their temperature limit may be re-located about 500 km further north under a climate that is 1.5 degrees warmer than it is at present. In summary it seems that such limits of temperature shift about 300 km northwards in the British Isles for each degree C rise in mean annual temperature.

Whether a northward shift of crops will actually occur is a matter of how agriculture might respond to changes in potential. It remains a possibility that, if farmers respond simply to changes in climate, fields of grain maize and sunflowers (which are a common sight in France not more than 100 km south of the English Channel) could be a feature of southern England and southern Ireland in the future.

However, while higher temperatures might extend the potential range of crops in northern Europe they would tend to decrease yields of some crops in the present core production areas. For example, yields of current varieties of winter wheat in south-east England and southern Ireland might be expected to decrease, in the absence of CO_2 fertilization ; and the positive effects of CO_2 could be cancelled out by temperature increases of above 4 degrees C (Squire and Unsworth, 1988).

Much would depend on changes in rainfall not only in the annual average amount but in its distribution throughout the year ; and we know little about how this might change. However, we do know that relatively small changes in rainfall could affect the map of types of farming quite substantially. To illustrate, the broad distinction between the arable east and pastoral west of England partly stems from differences in rainfall receipt between east and west. Very approximately the line of 780mm of rain per year divides the regions having more or less than 40% of farmland under cereals (Davidson and Sturgess 1978). A 20% decrease in annual rainfall, with the same seasonal pattern and regional distribution as now, would shift that 780mm line up to 100km westwards. Would that imply a westward extension of arable farming ? Conversely, would an increase in rainfall lead to an eastward shift of land-use belts ? The reality of this situation would be greatly complicated by other effects, for example on water for irrigation in the east or on the existing market for meat and cereals. But the suggestion is that quite small changes in climate could alter substantially the pattern of agricultural potential. Again, we should stress that how farmers respond to such changes in potential is wholly another matter.

A shift of the present belts of climate imply a shift in the potential for farming. In the northern hemisphere, particularly at high latitudes where agriculture is at present constrained by low temperatures warming may extend the range of staple cereals. In northern Japan, for example, the potential area of rice production may expand northwards and to higher altitudes (Yoshino ^Set al^S., 1988). The same may be true for wheat on the Canadian prairies and in the Soviet Union (though whether the soils and terrain will allow expansion is doubtful).

An insight into the possible scale of such impacts is offered by recent studies of possible shifts of vegetation zones. The initial indications are that temperature increases for a doubling of atmospheric CO_2 could lead to replacement of much of the boreal forest and tundra in north America by a northward extension of prairie grassland (Emanuel *et al.*, 1985). Again it should be emphasised that these are theoretical changes in vegetation distribution based on temperature and rainfall alone.

What of the possible changes in the uplands ? A 3 degree rise in temperature implies a rise in the potential limit to cultivation of about 500m (1640 feet) (Squire and Unsworth, 1988). Thus where excessive rainfall and exposure did not continue to restrict farming, there might be increased opportunity for cropping in the uplands. Probably more important would be the extension of the grazing season by one or two weeks in both spring and autumn, making it more profitable to improve and maintain upland grassland ; and higher temperatures could reduce the tendency for sedge and other rough grasses to invade improved land, making it easier to maintain. No figures are yet available for the increases in carrying capacity in the British uplands, but recent work in Iceland indicates that, under a 2 x CO_2 warming of 4^{o}C, the carrying capacity of improved grassland for sheep increases three-and-a-half times, and of unimproved rangeland increases two-thirds (Bergthorsson *et al.*, 1988).

In reality, the future of agriculture in northern Europe will depend very much on changes elsewhere, particularly in the present breadbasket areas of the world. There are indications that higher temperatures and reduced moisture on the US Great Plains and the Canadian prairies as a result of greenhouse warming will significantly reduce farming potential in this region (EPA, 1988). In Saskatchewan, in the prairies, spring wheat production may be reduced to 72% of their present levels for a temperature increase of 3.5 degrees C and no change in rainfall, and Saskatchewan alone accounts for 18% of the world's traded wheat (Williams *et al.*, 1988). We should not rule out the possibility, then, of northern and central Europe increasing its role as a producer to the world food market.

Effects on water, soils, diseases and pests

Before we can consider the responses that farmers might make to these changes in potential, it is important to consider the concurrent effects that changes in climate will have indirectly on crops and livestock, through changes in water for irrigation, changes in soils, and changes in the rate of losses to diseases, pests and weeds.

In southeast England, in order to offset increases evapotranspiration under a 3 degree warming it is estimated that rainfall would need to increase by 10% if shortage of water for use in agriculture were to be avoided (Beran and Arnell, 1989). The increased costs of water that might result could affect the amount of water not only used in irrigation, but also in spraying and in washing fruit and vegetables. The cost of construction of irrigation systems (in the order of £1000-3000 per hectare) could be one factor encouraging the westward and northward shift of cropping patterns. Reduced runoff in dry areas could reduce the dilution of waste, particularly of pesticide residues, with effects on toxicity levels of streams and thus on wildlife. In the uplands increased winter rainfall could increase leaching and reduce the pH of soils, and thus increase risk of flood and erosion.

Effects on soils depend much on the future seasonal pattern and intensity of rainfall, about which we know very little at present. An increase in thundershowers might increase runoff, thus increasing flooding and soil wash. But it also might reduce percolation thus decreasing the amount of water available for agriculture. Increased rainfall could increase the mineralisation of organic nitrates, allowing extra plant uptake ; but it could also increase leaching downwards of soil nutrients. In any case, quite small changes in rainfall could require sensitive alterations to the drainage of soils.

We can only guess at the implications for weeds, diseases and pests : warmer winters would extend the growing season of some weeks (*vide* the size of docks in spring 1989 after the extremely mild 1988-89 winter in northern Europe). For example, corn marigold, which flourishes in warmer and damper weather, could become more of a problem. In the south of England and Ireland scrubby, drought-resistant species (which already have a toe-hold on these islands) could increase their range (Grime and Callaghan, 1988).

Diseases which tend to break out more frequently in warm, damp conditions could also increase (such as rust, take-all and rynchosporium in cereals, and rhizomania in sugar beet).

Warmer winters could also increase the over-wintering of pests and increase their range. This could affect populations of aphids, pollen beetles (which are a pest on oilseed rape), and slugs (which attack young rape plants, particularly in wet autumn weather).

In summary, some of the benefits of warmer and drier growing seasons in the southern Britain and of warmer and wetter growing seasons in the northern Britain might well be offset by increased losses to weeds, diseases and pests. It is interesting to note that Icelandic agronomists, who expect the climate of Iceland in the second half of the next century to become similar to that of eastern Scotland today, estimate that yields of barley, now a highly marginal crop, may become cultivable throughout lowland Iceland due to longer growing seasons, but losses to diseases and pests (which are at present minimal in Iceland) could increase by as much as 15% (Bergthorsson *et al.*, 1988).

Possible responses in agriculture

While there are many uncertainties about how our climate will change in the future, there is one relative certainty about modern agriculture and today's farmers : it is that they have shown themselves capable in the recent past of adapting to a very wide range of conditions, both economic and environmental. The question, then, is not so much, "Can agriculture in the British Isles adapt to the Greenhouse Effects?" but "What kind of adaptations would be most appropriate and how can scientific research and government policy best help this process ?"

Firstly, many of the smaller changes in temperature and rainfall might be accommodated by adjustments to the timing of farming operations. For example, were the number of rainfall days to increase between (say) mid-February and mid-April (during the period when wet days can restrict the drilling of spring crops and the application of herbicides and nitrogen), it might be possible to shift these operations forward by one or two weeks. Advantage could thus be taken of a longer and warmer growing season that would allow harvest of cereals in mid- to late June rather than July.

Indeed, earlier maturation might be necessary in the south and east of England (if increases in temperature coincided with little or no increase in summer rainfall) in order to avoid losses from mid-summer drought. However, earlier emergence of the crop could make it more prone to damage from late frosts (if these were to occur with undiminished frequency). A switch to some Mediterranean wheat varieties which are more resistant to late season frosts might be appropriate if they yielded well under longer daylengths.

Any change in the number of workdays involved in ploughing, drilling, spraying or fertilizing due to changes in climate would alter the costs of operations quite substantially. Once more, the number of raindays is important here - and again we know little at present about how these may alter.

Changes in the pattern of weather events may bring new uncertainties to the task of deciding when to undertake given operations. While potential yields may not be diminished (and may be even enhanced) the uncertainties about the cost of obtaining such yields may increase.

Secondly, in addition to changes in the timing of operations, there could occur a shift from spring to winter varieties of cereals, in order to avoid a higher risk of moisture shortage in the early summer, and to take advantage of a prolonged growing season in the autumn and an earlier onset of growth in the spring. But while this option is open to the farmer in northwest Europe, the wheat farmer on the Canadian prairies would need to be sure that a reduction in winter snow cover would not remove the protection against frost damage that it affords at present. For example, the amount of winter wheat seeded in Saskatchewan during a dry period in the early 1980s increased from 18000 hectares in 1982 to 141000 hectares in 1983. Following dry conditions in the summer of 1984, when winter wheat outyielded spring wheat for a second year, an estimated 405000 hectares were sown to winter wheat. However, the 10-20 cm of snow cover required to insulate this crop from winter cold did not occur and a large area had to be reseeded in the following spring (Williams *et al.*, 1988).

Thirdly, it may make sense to switch to varieties of crops that have a longer or more intensive growing season requirement than our present ones. This would be particularly beneficial where varieties, developed for growing at present near their northern limit, are able to mature only at some loss of quantity or quality of grain. For example, experiments in northern Japan have shown that the early maturing varieties of rice grown there would benefit only to a small extent from a longer and warmer growing season. But late-maturing varieties at present grown 200km further south and which have a longer growing period requirement would, when grown in the north, be able to take greater advantage of the longer growing season and give substantially higher yields (Yoshino *et al.*. 1988.)

Fourthly, we can expect farmers in the British Isles to consider switching to new crops which have higher thermal requirements and are at present perhaps grown in the south of Britain or in central and southern France. Sunflowers could become a more profitable crop, in addition to grain maize, and perhaps even soya (which is at present grown in northern Italy). Navy beans, also grown in northern Italy and for which the UK imports all its needs at present, might also be cultivable under a climate that could occur in southern England and Ireland within the next 50 - 100 years.

Of course, any changes in the allocation of land to different crops would be influenced as much by changes in the potential for cropping elsewhere. If drier and warmer conditions obtained in Europe south of the English Channel, with reduced potential for the profitable farming of maize, sunflowers, soya, *etc.*, then this might well increase the competitiveness of such crops for farmland in Britain.

In the uplands of Britain, it might not be too far-fetched to imagine that the increased productivity of improved grassland, together with decreased productivity further south in Europe, could act as a spur to improvement of rough grazings. Due to higher temperatures and the direct fertilizing effect of CO_2, trees (both conifers and broadleaved) can be expected to grow faster, and do better at higher altitudes than they do now (unless windspeeds increase) (Cannell *et al.*, 1988). Together, these two enterprises could substantially increase demand for the uplands, increasing competition for land at present used for water catchment (which might itself need to be increased) and for wildlife and recreation.

Because these types of response will be interwoven in an incredibly complex way, it is probably not profitable to try to second-guess then in detail. We need only recall, for example, that by 2030 (the estimated $C0_2$ doubling equivalent time for greenhouse gases) the world's population will also have nearly doubled from its present levels : and this could well alter the structure of demand and prices for food. These should not, however, be taken to imply that we should do nothing.

CONCLUSION

It is clear that we need to know much more about a number of aspects of likely changes in climate, particularly : what is likely to happen to the weather at the regional and local (rather than global) scale ? How may rainfall alter, not simply on an average annual basis, but from season within the year ? And at what rate is the climate likely to change ?

At the same time we need to know more about how quickly agriculture can adapt to the kinds of climate changes we may experience, and how we can assist in that adaptation. What,for example,is the potential for adopting crop varieties at present grown elsewhere? Or should we be thinking of developing new varieties now, since these may take about 10 years to develop and adopt ? And what may be the cost of re-structuring agriculture : For example, what would be the cost of increasing irrigation to maintain in southeast England and southeast Ireland that kind of farming we see today, as against the cost of altering the type of farming there ?

These questions require several years more investigation before sufficiently detailed answers are likely to be available. It is probably unwise, therefore, to adopt a "wait and see" attitude, particularly if there are disagreeable time lags in the climate system which imply that we are, even now, committed to some significant amount of climate change and that the amount of change to which we will have to adapt will increase year by year the longer we delay in effort to reduce emissions of greenhouse gases. This suggests that, while continuing to pursue the scientific research to narrow the area of uncertainty about the greenhouse effect, we should also start thinking about the global agreements needed soon to reduce fossil fuel burning, improve efficiency in energy use and slow down the rate of deforestation.

Many of these policies of response would themselves have implications for agriculture in the future, such as policies to encourage afforestation in developed countries as a means of retrieving carbon from the atmosphere and storing it in trees ; or encouraging the growing of crops that can be used in the production of alcohol as a substitute fuel for coal, oil and natural gas ; or increasing the price of fuel to the consumer in order to reduce fuel consumption. The latter could significantly increase the costs of fertilizers for agriculture. The indications are that these policies will start to emerge within the next 4 or 5 years rather than 4 or 5 decades. Both the policies and the climate changes are likely to bring opportunities as well as costs for agriculture. It will be important to evaluate these opportunities and costs carefully, so that farming in northwestern Europe can respond in the most appropriate way.

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CLIMATOLOGICAL DATA ARCHIVE OF THE IRISH METEOROLOGICAL SERVICE - AN AGRICULTURAL RESOURCE ?

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Climatology is about the collection of information on the state and behaviour of the atmosphere and of the atmosphere's exchanges and interactions with the earth's surface. The most comprehensive datasets on the Irish climate are collected at the fourteen synoptic stations (Fig. 1) ; their dates of opening as full synoptic stations date from 1939 to the 1960s with quite a number opening in the 1950s.

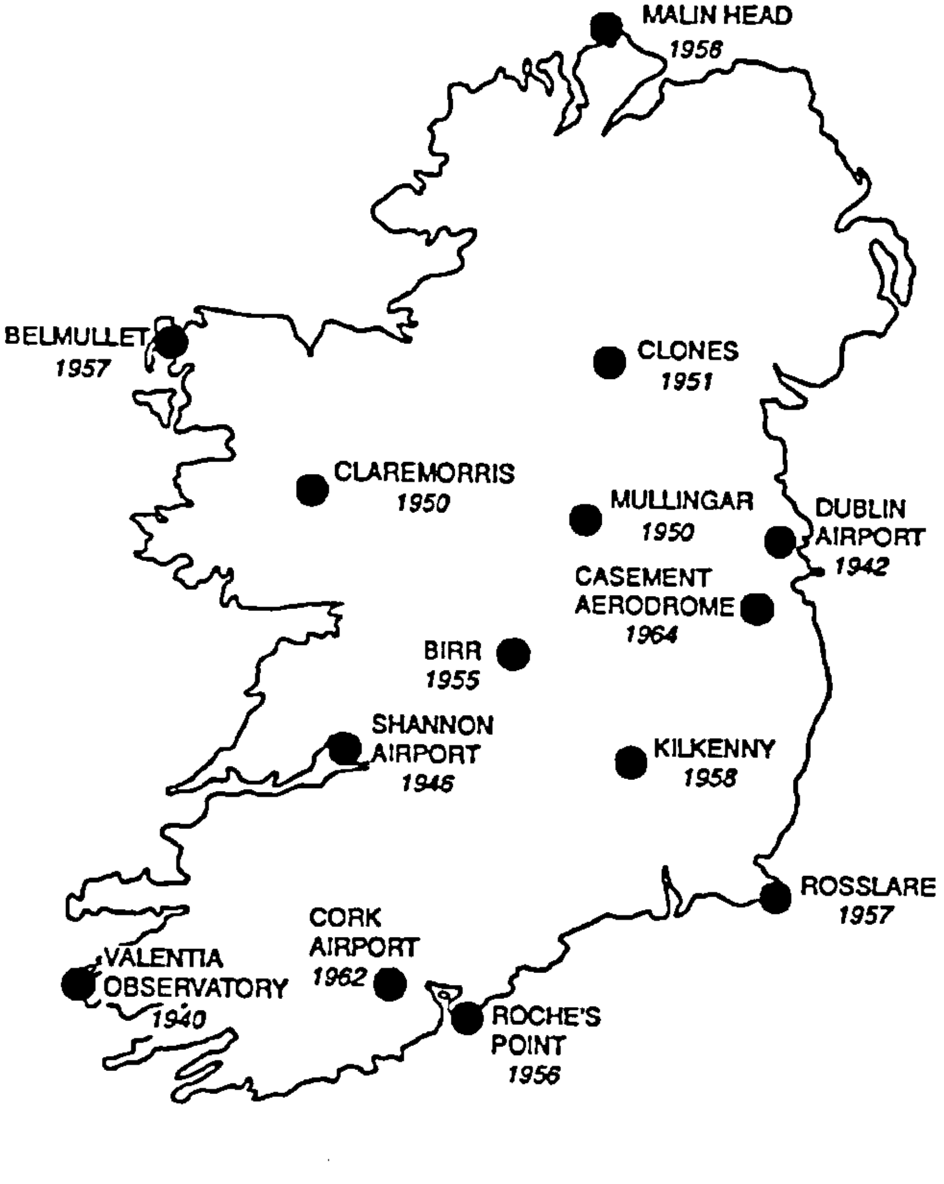

Figure 1 Synoptic observing stations. Dates indicate first full year of observations available on tape.

Data from these is available on an hourly basis for the following elements :

Temperature (Air and Soil),
Humidity,
Pressure and pressure tendency,
Rainfall,
Visibility,
Cloud height and cloud amount,
Wind,
Weather (present and past,) and
Sunshine,

Nine of the 14 stations participate in a programme of Chemical Analysis of Air and Rain; six participate in a programme of analysis of Radioactivity Levels, while seven measure Solar Radiation on horizontal surfaces.

All data is quality controlled. The computer system on which the Irish Meteorological Service holds the climate archive is due for replacement at the end of the year. It has acquired a RDBMS (relational database management system) with a powerful server and client workstations. It is planed to transfer all data to the new system within the next year or so. New and extended services including user-access to the new database are planned.

Climatological Station Network

At present the Irish Meteorological Service operates over 80 stations (Fig 2) but the quality is variable. In a recent assessment, they divided in almost equal numbers into the four categories : good, needing only minor adjustment, poor and very poor.

Most of the stations were opened in the late 50s or 60s. The vast majority take readings once a day at 0900 GMT. All read Air temperature, Humidity and Rainfall while some also measure Sunshine, Soil Temperatures, Run of Wind and Evaporation. The main elements available are Daily maximum and minimum air Temperatures and Rainfall which are read at all stations. Some also record Daily Sunshine and Daily soil temperatures. Quality Control of the computerised data has been carried out since 1966.

The files generated are binary files of all stations for each month as they were designed to generate the tables for monthly publication of climatological station data. Due to lack of demand the data are less readily available than that for synoptic station data. The RDBMS system will make the data cover readily available in the future.

Rainfall Stations

Daily rainfall information is collected from about 650 stations in Ireland. Of these 169 stations were found in 1988 to have an acceptable reading for each day and more than 200 of the stations are very reliable. About 600 are usable to some degree. Daily values back to 1941 are available on tape.

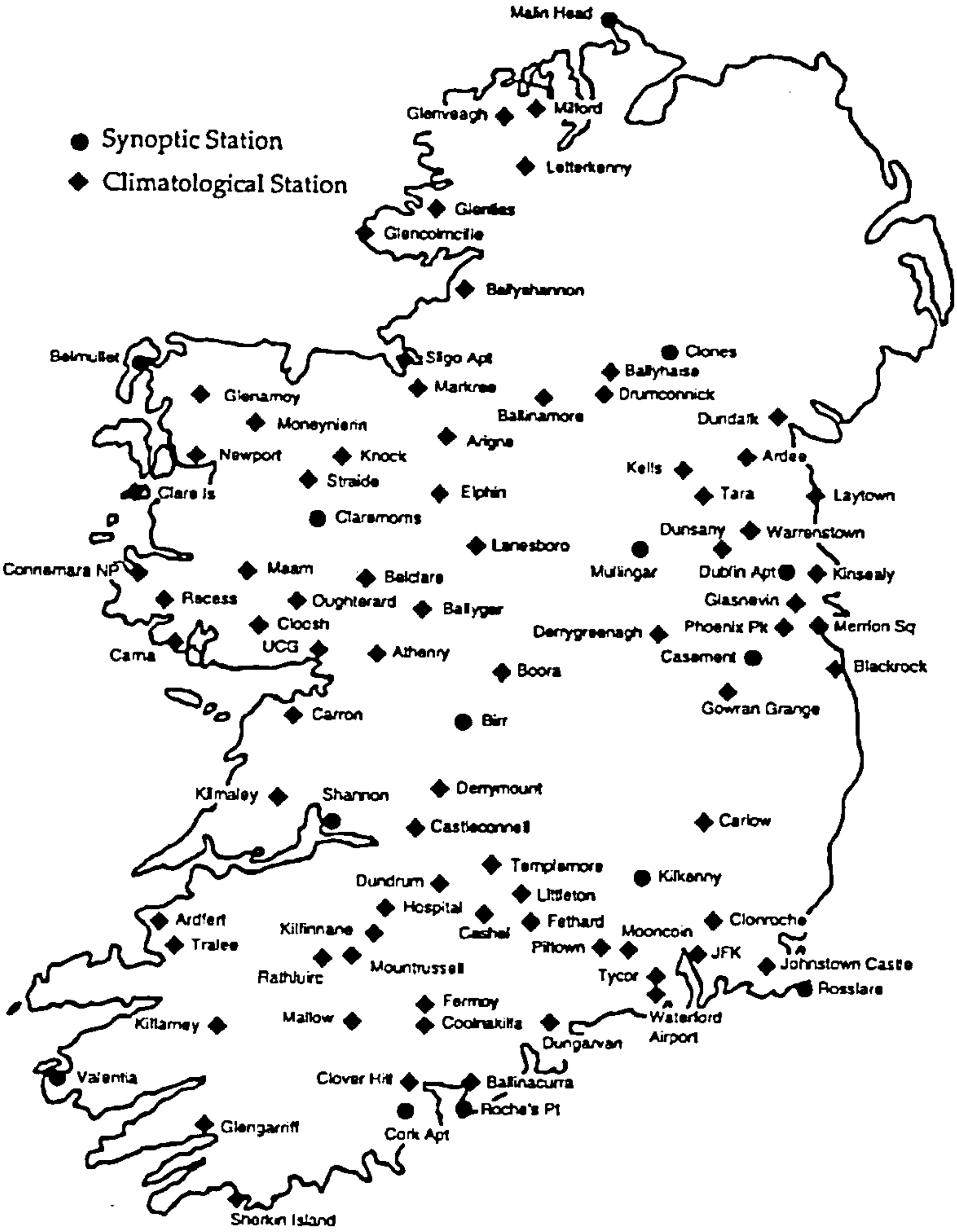

Figure 2 Current Climatological and Synoptic Stations. March 1992

More detail on rainfall events is available from the rain recorder network. Figure 3 shows that, besides the synoptic stations, we have about 75 other stations. In February 1990 it was found that of these 75,18 were satisfactory, 22 needed minor adjustment, 13 required major adjustment, 22 were out of action.

At the time of Chernobyl accident, in 1986, 15 operated without fault over a 3-month period. Charts from this network are available but, unlike the synoptic stations, hourly values are not extracted as a routine.

For hourly values of rainfall the 15 synoptic stations supplemented by the number of other recorded stations produce satisfactory information for hourly values of rainfall.

It is also possible to tabulate the daily maximum rainfalls for durations of between 15 minutes and 24 hours provided the falls exceed set thresholds - for the 60-minute rainfall, for example, the threshold is 6 millimetres.

Radiation Network

Figure 4 shows that 7 of the synoptic stations measure solar radiation on horizontal surfaces and gives the dates of commencement of recording. Belmullet measures global radiation only while the others measure both global and diffuse solar radiation.

Net radiation has been measured at Cahirciveen (Valentia Observatory) since 1971 and, courtesy of the Irish Committee of the International Hydrological Programme, it has also been measured at Kilkenny since 1982. Valentia Observatory is the main radiation station and it alone measures direct solar radiation and longwave radiation. Daily totals are published in radiation year books and hourly data is available on tape or disc.

Sunshine Stations

In addition to the synoptic stations, about 30 climatological stations record sunshine using Campbell-Stokes sunshine recorders. Hourly values of sunshine are routinely published for synoptic stations and daily sunshine totals are available for the other stations.

Sunshine totals can be used to supplement the radiation network. By using regression methods fairly accurate monthly totals can be generated especially when radiation and sunshine data recorded over the same period at a nearby radiation station can be incorporated in the calculations.

Sunshine has been much used as a proxy for radiation in agricultural studies. With an increasing trend towards automatic stations, radiation values should gradually become available from more stations in the years to come. So far, however, automatic stations have played little part in the Irish network of weather-observing stations.

Figure 3 Current Rain Recorded Stations
March 1992

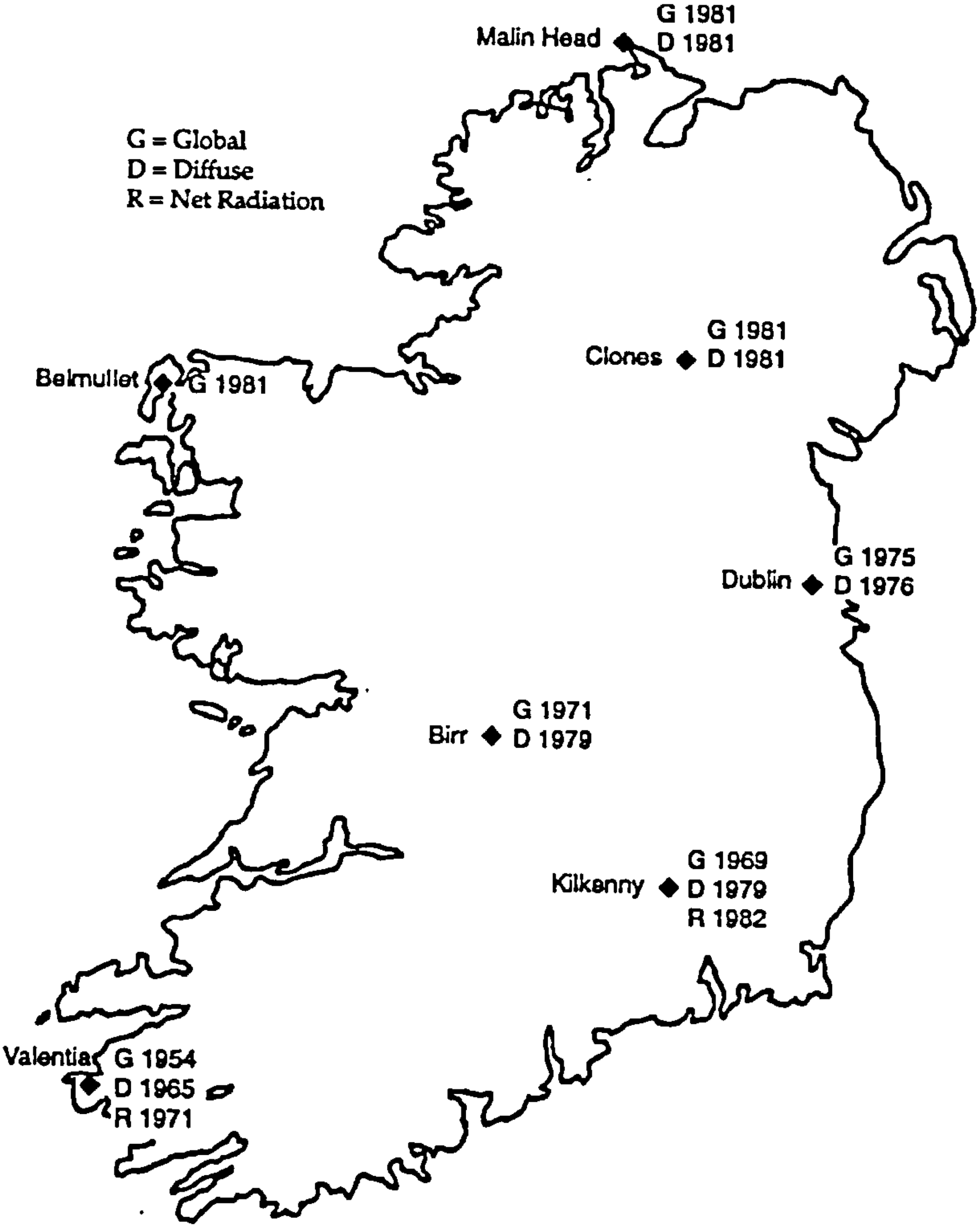

Figure 4 Solar Radiation Station Network
March 1992

Marine Data

The computer archive consists of reports from 5 Lighthouses, Oil Rigs, Ships and Buoys.

In addition estimates of wave heights generated by a computer model are stored. More detailed information on the archive is available from the Marine Section of the Irish Meteorological Service.

Upper Air Data

Vertical sounding of the atmosphere is carried out only at Valentia Observatory and data on winds, temperature and humidity aloft dating back to the 1940s are available on tape.

Evaporation Network

Since 1971 the Meteorological Service has published 10-day soil moisture budgets based mainly on Thornthwaite Evapotranspirometers located at Johnstown Castle, Carlow (Oak Park), Dublin (Kinsealey), Valentia Observatory, Ballinamore and, until recently, at Glenamoy. (Figure 5) Data are drawn from grass-covered lysimeters and a Class A pan network. This network dates back to the 1960s but is now in a poor state with some of the pans requiring replacement. Extensive correlation of evaporation from these shallow, unlagged pans with water loss from lakes and crops, mostly on a seasonal or annual basis has been carried out.

The Penman formula is used by the Service to make monthly estimates of evapotranspiration at synoptic stations and serves as a check on the lysimeter values. Because the grass on the lysimeters is kept well supplied with water they suffer from an oasis effect in warm weather. For this reason, the Penman estimate is regarded as a standard because the formula has a sound physical basis. However, many coefficients of the formula are difficult to evaluate accurately and so to regard it as a standard seems questionable. However, for comparison studies it is much used since lysimeters are neither plentiful nor standardised.

Long-term Stations

Recordings which commenced before the turn of the century is regarded as long-term. The elements usually available are : Air Temperature, Rainfall and Sunshine.

The Stevenson Screen was introduced about 1880. Air temperatures recorded before 1880 must be carefully examined and the method of recording determined, if possible. The Campbell-Stokes sunshine recorder was also introduced about that time and the exposure of raingauges was also in accord with modern practice.

The long-term stations may be placed in the following order of importance :

Valentia Observatory
Phoenix Park
Malin Head
Roche's Point
Markree Castle
Birr
Belmullet-Blacksod

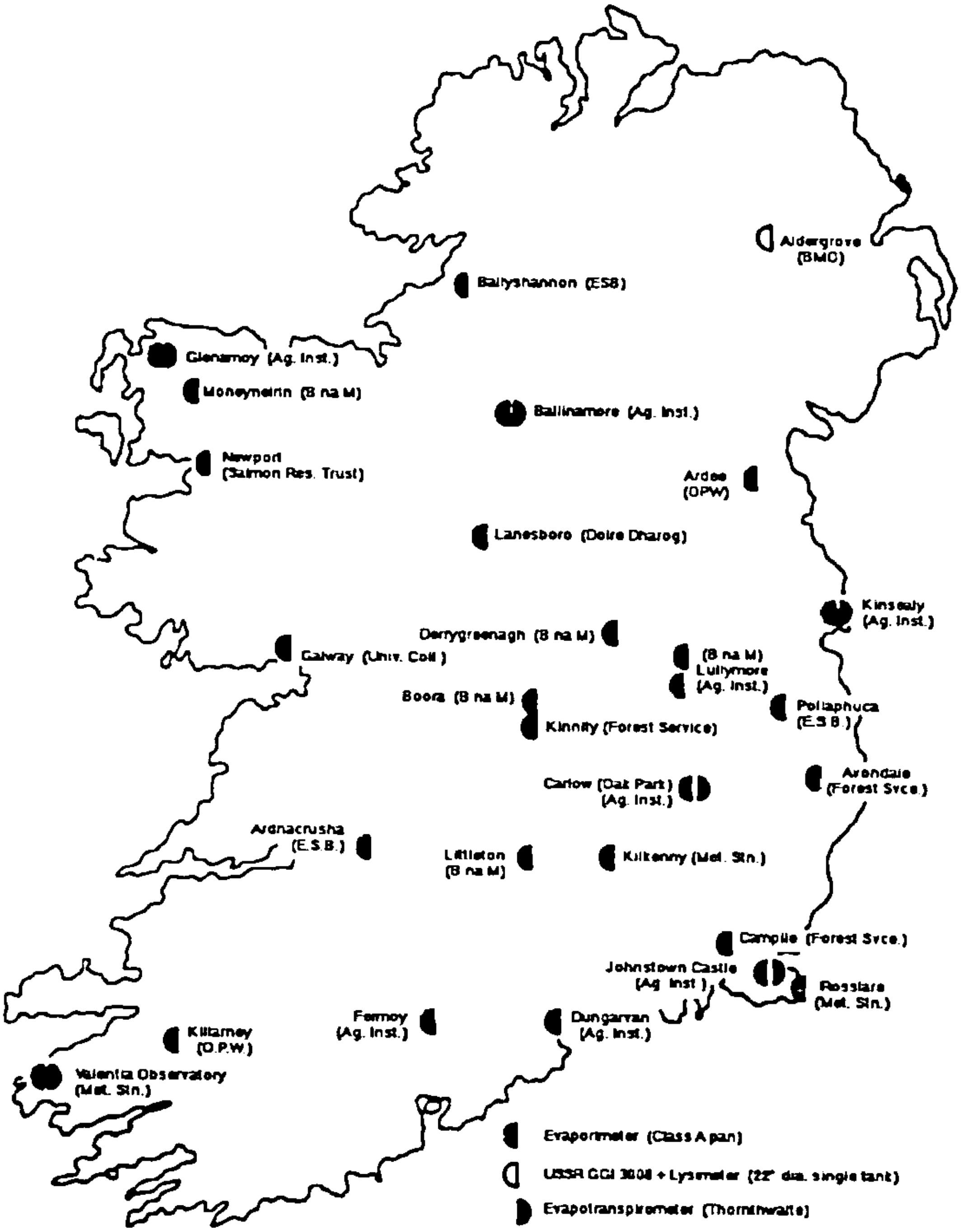

Figure 5 Locaiton of evaporimeters and evapotranspirometers in Ireland, February 1992

Valentia Observatory has been at its present site on the mainland since 1892; before that it was located on Valentia Island. Hourly values for various elements have been published for about a century. Post-1941 data are available on computer.

Phoenix Park has the longest record and daily values back to 1880 are available on tape.

Malin Head and Roche's Point have been recording temperature and rainfall since the 1870s. Sunshine is available at Malin Head since 1914 but sunshine recording did not commence at Roche's Point until the mid 1950s.

Markree Castle has had continuous records since 1875 but there have been a few lapses in recent years including the cessation of sunshine recording. Nonetheless, it is a valuable record of weather in the northwest.

Birr has had continuous records since 1872 but there have been several changes on site which make it difficult to extract a homogeneous series for any weather element.

There are over 100 years of weather record in the Belmullet-Blacksod area but so far very little of it has been analysed and processed.

Synoptic Climatology

The British Meteorological Office started publishing synoptic weather charts in the Daily Weather Report in 1872. The Irish Meteorological Service library in Glasnevin has numbers dated to the early 1930s while Valentia Observatory has copies from 1915 onwards. The BMO started including an upper air section from 1919 but the main body of upper air data dates from the 1940s and is available in Glasnevin. However, the BMO ceased publication of the Daily Weather Report in the 1980s. To maintain the continuity of the series, use has been made of the German Weather Service, North Atlantic weather charts, both surface and upper air but their format is too large to allow convenient use.

Using charts of the hourly weather reports from our synoptic stations a coding system allows quick assess to the variation in weather conditions over Ireland at a given hour ; a computer map of the 15 reports for any hour may also be generated.

Non-Archived Data

While the Irish Meteorological Service makes extensive use of satellites and radar for forecasting, neither type of data is archived at present. However the new RDBMS has the capability to archive such data types and to extract information from such images.

Radiation

No data exists on the Spectral Composition of solar radiation. As there is considerable concern about levels of UV radiation, this is a serious lack.

There is much interest nowadays in levels of ozone, both tropospheric and stratospheric and also in the other greenhouse gasses. The station at Mace Head, which is run by UCG, is improving our knowledge of some of these parameters but the Irish Meteorological Service does not have any data on ozone or greenhouse gas levels in Ireland. Neither does it have data on hydrology, river flow, sea-levels, ground water and water quality.

AGRICULTURAL USES OF CLIMATOLOGICAL DATA

There are both operational and planning uses for climatological data, sometimes in tandem with weather forecasts.

Operational :

The Potato Blight Warning system, which has been in operation for over 40 years, depends on the assessment of the suitability of past weather for the build up and spread of the disease as well as a forecast for a few days ahead. The warning system for cereal diseases, such as mildew and septoria, operates similarly.

Ollernshaw's Liver Fluke Index differs in that the assessment is of the suitability of the season for the snail which acts as host to the fluke. The most important weather parameter is the excess of rainfall over evaporation which gives an indication of the wetness of the snail habitats.

The T-Sum 200 Index is a cumulative index of mean air temperature, depending solely on past weather and is used as an indicator of when fertilizer should be applied to field crops.

Parameters such as the soil moisture deficit are used as inputs to crop-growth models. This type of modelling has been much in vogue recently and should continue to be so.

Planning

Climatological data enables the calculation of the number and variability of work days suitable for weather-dependent tasks such as spraying or autumn cultivation. The length and quality of past growing seasons can be assessed as can the likelihood of damaging weather conditions for a crop or the need for irrigation.

The length of the frost-free season or the chance of frost at a sensitive growth-stage can also be derived.
Wind chill indices can be used in the same way and values related to such incidents as lamb mortality and then be used as the basis of a forecast warning system.
Wind chill studies may also be used to determine the best directions to choose when siting windbreaks.

At the other extreme, heat stress indices could be calculated for periods when pig and chicken mortality was high in intensive production units. If present fears of future warming are realised, then the frequency of heat stress incidents is likely to increase.

Forecasting presumes that the past may be used as an indicator of the future - it is in any event the only information available
and must be a major part of the basis for prediction.

Ontario Heat Units

This unit is a temperature index of the seasonal heat requirement of maize and the criterion used is that 2400-2500 units are needed over the May-October period if 30% dry matter is to be attained. Figure 6a a shows that, on average, parts of the south and east of Ireland are suitable. However, if the grower requires to meet the criterion 9 years in 10, Figure 6b shows that in the past the threshold exceedence of 90% of the time was not met anywhere in Ireland. However, in a warmer climate this might well change.

Sensible Heat Loss of Lambs and Sheep

The core temperature of a sheep is in the very high 30'sC and so in Ireland it loses heat to the air. When it has to expend no energy to keep its core temperature steady it generally loses heat at a rate of about 55 Watts per square metre. When it loses heat at a much higher rate it must expend energy to maintain its internal temperature and so is under stress. Figure 7 shows the average heat loss per day for Claremorris and that lambs suffer the highest losses since they have the thinnest coats. Such models of heat loss can be used with mortality data to set criteria for the occurrence of seriously stressful conditions and then used as the basis of a forecast warning service.

Past and Future

Predicting the future has always been an endeavour of mankind. Currently there is great interest in predicting future climate. A classic definition of climate (Hann 1903) is the sum of meteorological phenomena which characterise the average conditions of the atmosphere at any one place on the earth's surface. Historically, the emphasis has been on summary statistics, particularly the average. There was until recently broad acceptance of the notion that over periods long compared with the human lifespan climate is essentially constant. In statistical work this is a very convenient assumption as we can regard ourselves as drawing from the same population with variability caused by random fluctuations of the climate system.

The modern view recognises the importance of long-term (30 to 100 years) averages but places greater emphasis on other descriptive statistics such as variability, frequency of occurrence and measures of persistence. This is not to say that the early climatologists were not concerned with these measures. Rather with the limited computing power available calculation was then much more difficult. Risk assessment is now a prime concern of climatology and extreme-value theory has developed rapidly in the last forty years.

But the major recent change is that we are much less inclined to think that the climate of the net 50 years will be well described in its essentials by that of the last 50 years. However, it is difficult to say what constitutes a change in climate. In statistical terms, even when we sample from the same population we may get very different indications

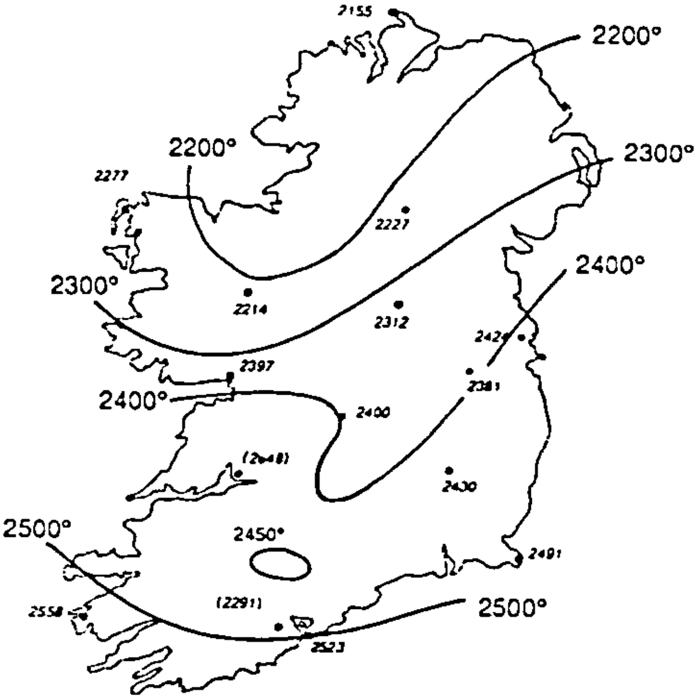

Figure 6:(a) Ontario Heat Units - Averages (1958-82) May 1 - Oct 31

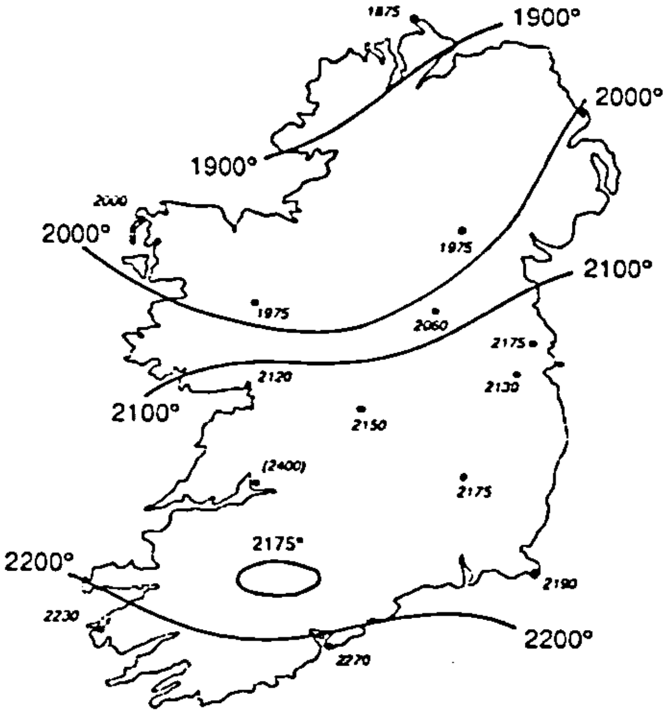

Figure 6:(b) 90% probability of exceedance, May 1 - Oct 31

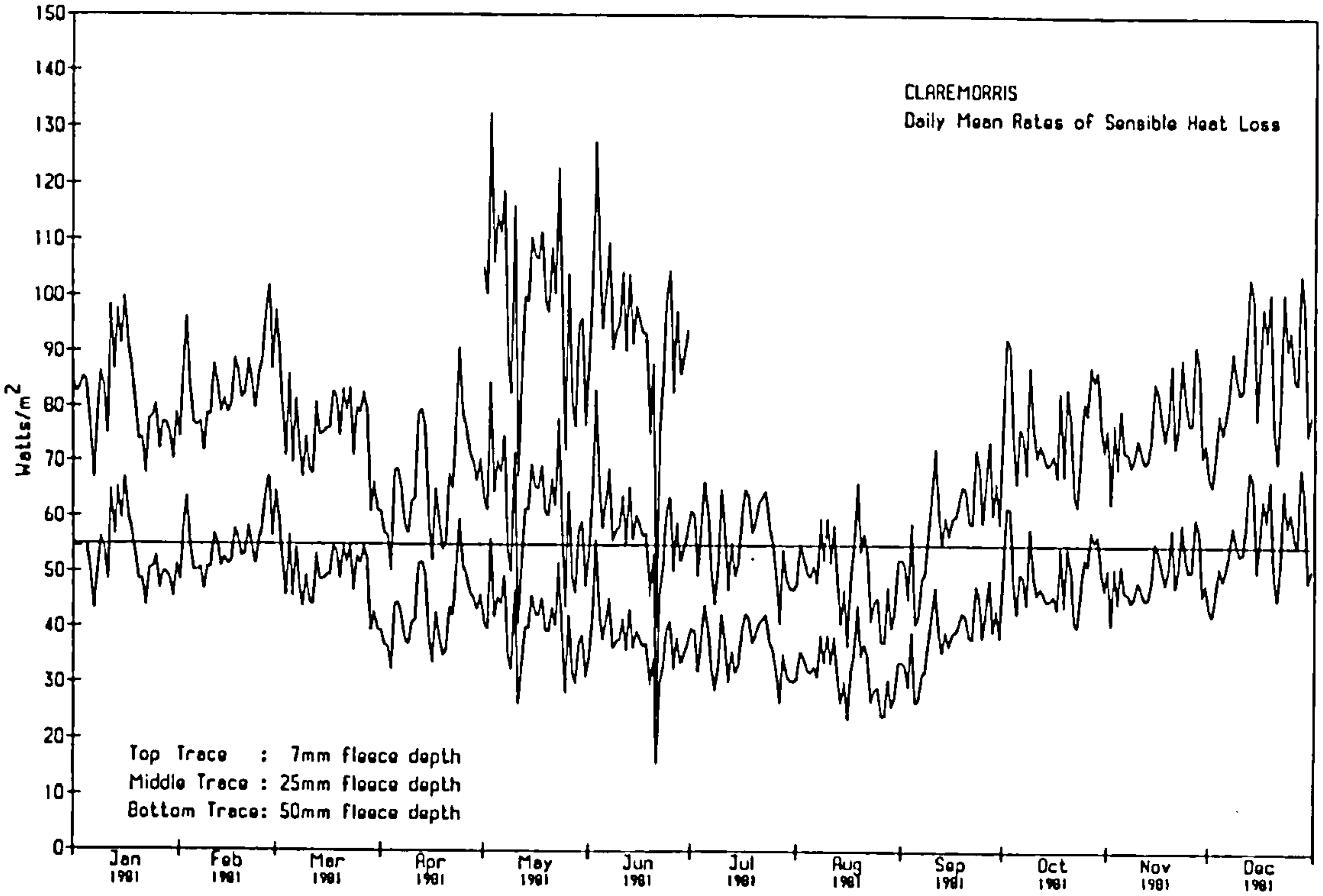

Figure 7 Daily mean rates of sensible heat loss, Claremorris, 1991 for 3 thickness of fleece

from successive samples of the parameters describing the population. This makes it difficult to interpret changes, in, say, the mean temperature or temperature variability as definite (permanent ?) shifts in climate.

We may suspect that the climate is changing in a non-random way through time but can we quantify this ? Looking at the graph of the air temperature of the Phoenix Park (Fig. 8) and using the mean as a reference, the series shows (1) a tendency for increase from about 1915 to the 1940s (2) a period of erratic decline until the 1980s which was a mixture of the warmest years since the 1940s and the coolest year since the 1890s.

The global temperature series broke all previous records about six times in the 1980s - statistically a more remarkable series of events. Ireland did not follow the global pattern as our highest mean annual temperatures were higher in the 1940s.

STATISTICAL EXAMINATION OF CLIMATE CHANGE

The first step in the statistical examination of climate change is to examine the time series to discern any pattern or structure. After this exploratory analysis various (statistical) models may be treated for fit to the data. Suppose that you find a model (perhaps with a random component) that closely reflects the (long-term) movements of the series may you then extrapolate on into the future with confidence. Sceptics allege that forecasting the future from the past is like driving a car blindfolded on the instructions of a person looking out the back window. However, successful statistically-based forecasts of complicated systems have been made but they are of much shorter term than those required in climate change studies.

Another related statistical method is to select the physical mechanisms thought to be of importance and to relate series reflecting their variations over the period to the variations of the climate parameter of interest. Two recent studies illustrate this approach :

(1) Christenson and Lessen (1990) used the Gleissberg cycle as an index of solar activity to explain the variations of the mean Northern Hemisphere temperature over land. Figure 9 shows that this single variable closely follows the air temperature series over a long period. Given the considerable and non linear variation of the temperature series this is most impressive.Greenhouse gasses are nowhere invoked. Does this mean that they do not have an important role in determining climate ? Unfortunately statistical studies are not conclusive in this regard. Instead they test the plausibility of certain assertions and are indicatory rather than conclusive.

(2) To model the global mean air temperature Schönweise (1991) uses four causal variables : greenhouse gas concentration, volcanic activity, El Nino-Southern Oscillation forcing and an index of solar activity which presumably was not the Gleissberg cycle. Figure 10 shows a good measure of agreement. Schönweise considers the ENSO forcing of minor importance and is left with three explanatory variables.

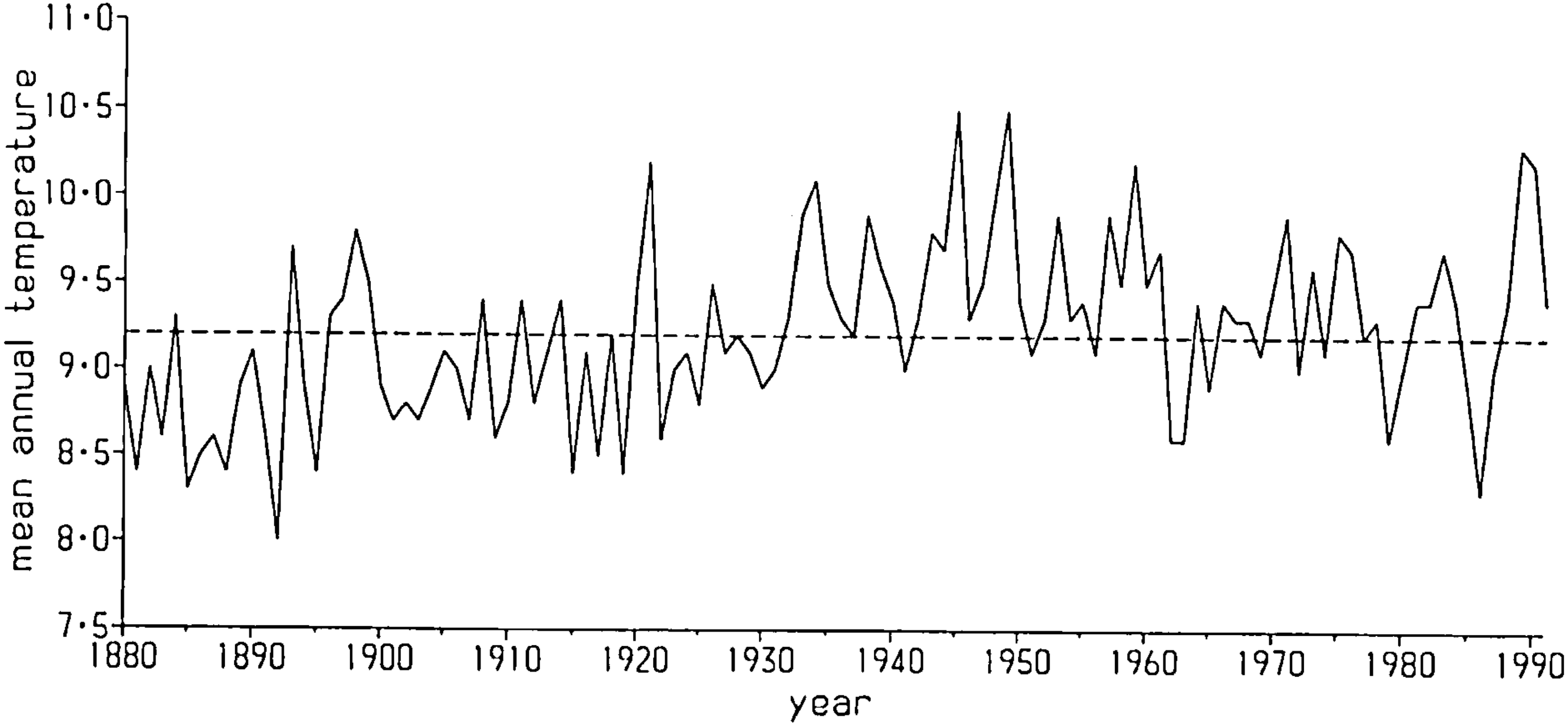

Figure 8 Mean annual temperature at Phoenix Park (1980-1991)

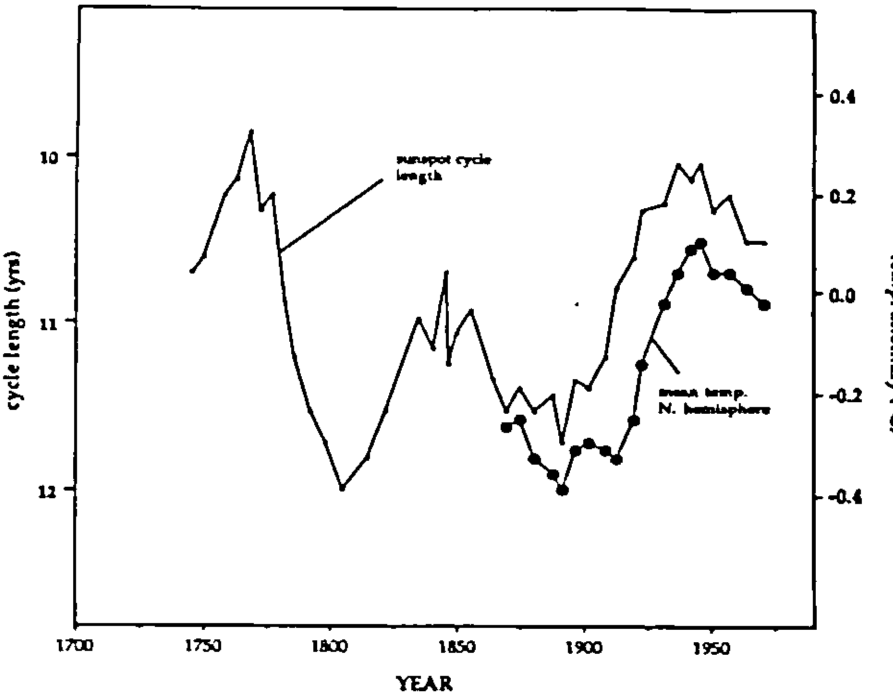

Figure 9 Smoothed sunspot cycle lengths from 1940 to 1970 (lelf-hand scale) and Northern Hemisphere Mean temperature (right-hand scale)

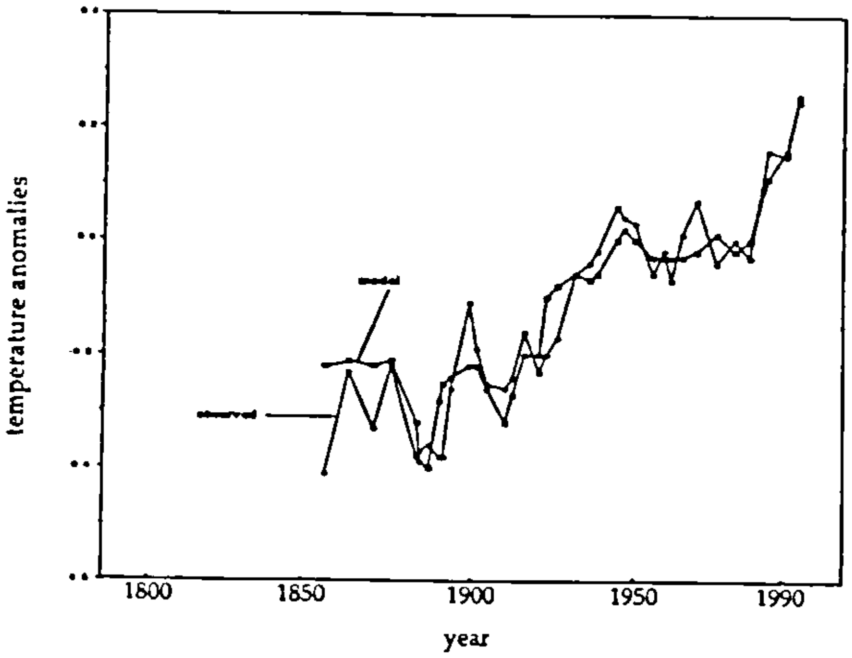

Figure 10 Observed global mean surface air temperature anomilies (land and marine data) based on deviations from the 1950-1979 reference period compared with Schonweise's model

This exercise reinforces the point that great care is needed when drawing conclusions from such studies. Likewise we should be careful in interpeting what the records say about temperature extremes in a warmer climate. One possible approach is to appeal to the peak-over-threshold method of extreme value theory which indicates that these follow a distribution and that the parameters are :

(1) the rate of exceedance of the stated threshold which would increase
(2) the mean exceedance which should also increase
(3) the shape parameter - here difficulties arise because it is a very difficult parameter to estimate accurately. If it remains unchanged, then by increasing the rate and the mean value of the exceedance we can get a rough notion of extremes in an altered climate.

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CLIMATE CHANGE : PROSPECTS AND CONSEQUENCES FOR IRISH GRASSLAND

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ABSTRACT

Climate warming, due to increased concentrations of greenhouse gases in the atmosphere, is likely to lead to significant increases in grassland production in Ireland. Production will be stimulated by a direct fertilizer effect of CO_2, the most important of the greenhouse gases, and the increase in temperature. The size of the response can be estimated from experimental manipulation of the environment, historical evidence from past climate change and using weather-driven simulation models. These combined approaches suggest that by 2030, when there will have been an eqivalent doubling of preindustrial levels of CO_2, grassland production in Ireland will be about 18% higher due to the temperature increase and a further 10% higher due to the direct CO_2 effect. Furthermore, the models suggest that the grazing season could be up to one month longer and the stocking rate on farms could increase by 30 to 40% to fully utilize the extra grass production. These grasslands will also increase in their importance as a sink for atmospheric CO_2.

INTRODUCTION

The general scientific consensus is that a significant change in world climate will occur during the next century, largely due to an increased concentration of greenhouse gases in the atmosphere generated by anthropogenic activity (IPCC, 1990). The most important greenhouse gas is carbon dioxide (CO_2) which is increasing at about 0.5% annually. Furthermore there is likely to have been an equivalent doubling of its preindustrial concentration by about 2030 if emissions due to fossil fuel burning and deforestation continue to rise along their present path. Atmospheric general circulation models (GCMs) have been used to predict the climate expected for an equivalent doubling of the CO_2 concentration. These models give rather poor resolution at the regional and local level, but for north-western Europe it is predicted that by 2030 the average annual temperature will increase by 2^oC, with warming probably more pronounced in winter than summer. Possible changes in rainfall are even less clear, but it appears most likely that precipitation will increase by 5-10% in winter and decrease by 5-10% in summer. It is important to emphasise the uncertainty of these forecasts, particularly for a small landmass such as Ireland, but at present they represent a 'best guess' on which to assess the hypothetical impact of climate change on Ireland. This 'climate change scenario' has therefore been used to assess the impact of future climate change in Ireland on agricultural grasslands. In a recent review Brereton (1992) has shown that on well-drained soils meteorological factors are the main cause of present regional variations in grass yields with variation in soil and sward composition being relatively less important. It is to be expected therefore that any future change in climate will have significant effects on grass production.

ASSESSING THE EFFECTS OF CLIMATE CHANGE

When considering the impact of climate change on grasslands it is important to distinguish between two broad types of effects. The first is the fertilizer effect of increased atmospheric CO_2, and the second is the effect of change in weather, primarily temperature and rainfall, on crop growth and productivity. Both will change concurrently, but here we review their separate effects initially. Also, although the primary impact of climate change on grassland will influence production, it is important to appreciate that the agricultural output from grassland is not grass but the meat and milk which are produced by the animals which consume the grass. An assessment of the influence that climate change has on grass utilization throughout the year is likely to be an important measure of impact on agricultural grasslands.

To assess the effects of climate change on grassland, three approaches can be used. These are (i) the experimental approach, where grasses are exposed to a controlled environment of CO_2 concentration, temperature and rainfall which might simulate a future climatic scenario, (ii) the historical approach, where information is gathered on production measurements made when climatic conditions have changed over time at one location and (iii) the modelling approach, where process-based simulations of grassland systems are run under a defined future climatic scenario.

EXPERIMENTAL APPROACH

Many experiments where grass has been grown under defined temperature and moisture conditions have been carried out. There have been fewer experiments where the effect of growth at elevated CO_2 has been investigated. The effects of temperature have been reviewed by Robson *et al* (1988) and water relations by Jones (1988). When perennial ryegrass is grown at elevated CO_2 levels there are marked increases in yield and tillering. For example, when CO_2 was increased from 350 to 680 ppmv there was a 78% increase in yield and 35% increase in the number of tillers (Jones, 1992). Table 1 summarises studies which have investigated the direct effect of elevated CO_2 on the growth of perennial ryegrass. In other grasses the response may be less marked due to the lack of sinks for the extra assimilates produced in photosynthesis. For example, Hunt *et al.* (1991) found that *Festuca rubra* showed no increase in yield at elevated CO_2. Also the consequences of long-term exposure to elevated CO_2 levels (several years) is still uncertain. This evidence will only come from long-term experiments where grass plants are continuously exposed to elevated CO_2 levels. However these experiments have not been done yet. At present, our information comes largely from controlled environment experiments where single plants or small communities have been grown for relatively short periods of time at elevated CO_2. Longer term experiments where grasses are grown in the field in open-top chambers at elevated CO_2 are underway (Ashenden, 1992) and experiments using FACE (Free air CO_2 enrichment) are planned.(GCTE News, 1991).

Table 1. The response of shoot dry matter production in Perennial ryegrass *(Lolium perenne)* to elevated CO_2 concentrations.

Cultivar	CO_2 increase (treatment/control) (ppmv)	Yield change (%)	Source
Melle	626/358	+19	Nijs *et al* (1989)
Talbot	700/350	+37	Hunt *et al* (1991)
Melle	680/340	+10-20	Ryle *et al* (1992)
Melle	680/350	+78	Jones (1992)
Printo	547/340	+49	Overdieck (1984)

HISTORICAL EVIDENCE

Several researchers have suggested that significant increases in primary plant productivity may have already occurred as a result of the increase in atmospheric CO_2 content that has taken place over the past two centuries (Gifford, 1979; Allen, 1987). For example, the yields of soybean may have increased by 13% from about 1800 AD to the present due to global carbon dioxide increase (Allen, 1987). Of course, there is at present no independent way to confirm the reality of these estimates. There have unfortunately been very few long-term measurements of production at a single site in order to test this hypothesis for grasses. However, there has been one study on a grazed grass-clover pasture at the Grassland Research Institute, Hurley, U.K. which was started in 1954 and has continued until 1991 (Tyson *et al*, 1990 and pers. comm.). Figure 1 shows the spring yield of these pastures over this period which has seen an increase in ambient CO_2 levels from 315 to 355 ppmv. There have been the expected year-to-year variations in yield but the general trend has been upwards from about 3 to almost 5 t ha^{-1} Spring yields were chosen in this example as they are less susceptible to water stress effects which can severely limit summer growth in some years (Jones, 1988). Tyson *et al* (1990) ascribe the increasing production in spring to the improving fertility of the soil but it is possible that some of the increase is explicable in terms of a CO_2 fertilizer effect. Results from the experimental work outlined above would suggest that the changes in ambient CO_2 levels between 1954 and now should lead to a 10-20% increase in yield. We would therefore argue that increasing CO_2 levels have made a contribution to the observed increase in yield although they are not the only, and probably not the most important, factor involved. It is clearly very difficult in grasslands to detect unequivocally a response signal to increasing CO_2 levels and probably more difficult than other types of vegetation such as woodlands, where tree-rings can be measured over longer periods of time, and agricultural cereals and pulses, where harvestable yield in grain or seed is more easily defined.

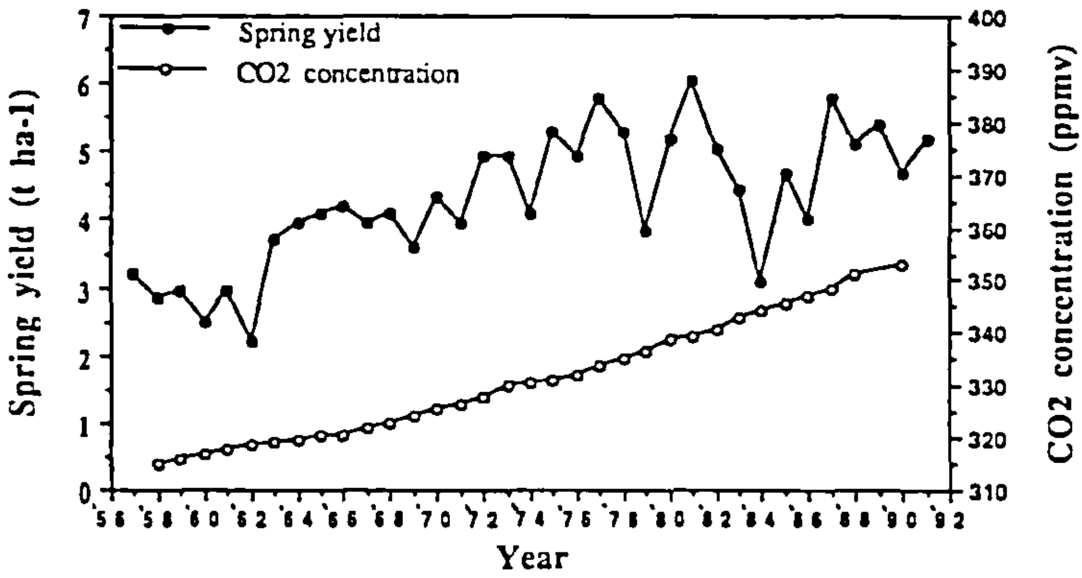

Figure 1: **Annual spring dry matter yield of ryegrass-clover pastures at Hurley, U.K. (from Tyson et al., 1990 and pers. comm.) and annual average atmospheric CO_2 concentration (from IPCC, 1990).**

WEATHER-DRIVEN MODELS

Mechanistic models of crop growth provide a quantitative description of production by incorporating an understanding of the mechanisms of the component processes and their interactions. Two approaches to predicting the response of production to climatic change are used here to illustrate some of the possible responses of grasslands to future climatic conditions. These can be broadly described as (1) an analytical approach where production is simply a function of light interception and conversion efficiency as proposed by Monteith (1977) and (2) a dynamic modelling approach which incorporates the major physiological determinants of productivity and their responses to environmental variables. Both are weather-driven models of grass growth but in the examples used here they predict production and the consequences on different time scales, the first as seasonal and annual production and the second over forty years or more.

The analytical model

Monteith (1977) proposed that the dry matter production of agricultural crops could be described by a simple function of light interception and conversion efficiency. Brereton and Hope-Cawdery (1988) have developed this model to simulate herbage growth using the basic equation

$$Y = eR/V$$

where:

Y = herbage dry matter accumulation rate (kg ha^{-1} d^{-1})
R = radiation receipt at crop surface (MJ ha^{-1} d^{-1})
e = conversion efficiency
V = energy content of plant biomass (MJ kg^{-1})

In this model the value of e depends on current temperature.

The model has been used recently by McGrath *et al* (1991) to predict grass production in Ireland under simulated conditions of climate change where the mean temperatures increase by 2°C and there is an increase of 10% in rainfall in winter and a decrease of 10% in summer. Under these conditions the model predicts that the potential for grassland production in Ireland will rise by approximately 18%. An increase in temperature of 3°C and annual rainfall of 15% results in a 38% increase in yield. These predictions do not include the fertilizer effect of increasing CO_2 levels which will accompany the temperature and rainfall change. If it is assumed that these climate changes will occur by about 2030 the atmospheric CO_2 levels are likely to be about 430 ppmv; 22% higher than at present. The fertilizer effect of this increase in CO_2 might be expected to increase yield of grasses by about 10% above present levels in summer although this may be reduced at lower winter temperatures.

The Brereton and Hope-Cawdery model, because it can predict the seasonal pattern of production, can also be used to investigate in more detail the consequences of increases in grass yield for farm management practices. In the following example it is used to examine the changes in stocking rate and the seasonal management of grassland that would follow on climate change.

The model has been used to predict grass production on an intensive dairy farm in South Munster, Ireland using present climatic conditions (30 years average of air temperature, rain and bright sunshine at Cork city) and a scenario for 2030 where mean temperatures are 2°C higher and rainfall in winter 10% higher and in summer 10% lower than at present. The fertilizer effect of CO_2 has been incorporated by assuming a 22% stimulation of growth when air temperatures are greater than 10°C, and 11% when temperatures are less than 10°C.

At present the farm is assumed to have a stocking rate of 2.5 to 3.0 cows ha^{-1}. The cows calve in February and weigh 550 kg at the start of lactation. Lactation ends in November and the total milk yield per cow is 5000 litres. Nitrogen is applied to the grass at 300-400 kg ha^{-1} y^{-1} and 5 t ha^{-1} of silage is cut in mid-May and early June with about 55% of the farm used for silage at the first cut and 40% at the second. Purchased feed, at 2 t ha^{-1}, accounts for only about 10% of total feed consumed. The aim of the modelling exercise is to find a stocking level at which (i) all the grass production is utilised at a rate that does not restrict animal performance, and (ii) the area not needed for grazing in summer is great enough to produce all the silage needed for winter.

The procedure is to calculate for a series of stocking rates the area needed for grazing throughout the year. This area is calculated as the ratio of herd intake to herbage growth rate. When the ratio is 0.5 only half the farm is needed to feed the cows at that moment and the remainder is available for silage. When the ratio exceeds unity then cows need to be fed silage or purchased feed. In this simulation the first day in the year when the ratio is 1.0 is defined as the start of the grazing season and the last day when the ratio is 1.0 is defined as the end of the growing season. The remainder of the year is the indoor feeding period and the supply of silage feed during this time was calculated by integrating the dry matter production in excess of that needed for grazing. Animal intake was calculated using the data in Bulletin No. 33 (MAFF,1975).

The optimum stocking rate for the farm is where the supply and demand for silage is equal. The effect of the climate change scenarios imposed is to increase the stocking from about 3.0 to 3.75 cows ha^{-1} excluding the CO_2 fertilizer effect, and to 4.25 ha^{-1} when it is included (Figure 2).

When the farm is stocked at the optimal rate there is little change in the general shape of the curves of seasonal trend in the area needed for grazing (Figure 3) but there are important changes in the timing of the start and end of grazing. The start of grazing is brought forward by about 20 days and the end of grazing is delayed by about 14 days when the CO_2 fertilizer effect is included. If this effect is excluded the end of season extension of grazing is reduced to only about 7 days but there is less of an effect on the start of the grazing season. This is because temperatures are lower at this time, which reduces the CO_2 effect. A further effect of the climate change scenario in the present simulation is to markedly increase the requirement for supplemental feeding in mid-summer. Under current climatic conditions the amount of supplementation is negligible but with the temperature and rainfall changes a supplementation need of about 15% for two months in mid-summer is predicted. This is due to the combined effects of lower rainfall on grass growth and of the higher stocking rate on demand. When the CO_2 fertilizer effect is included, however, the level of required supplementation falls to less than 10%. Adjustments downwards in stocking rate could, of course, reduce the size of this mid-summer deficit and because the silage demand in winter would be reduced the grazing season could begin earlier and end later.

It can be seen therefore that the climate change scenarios used in the model do not suggest radical restructuring of farm systems. The main effects would be to extend the grazing season by about one month while allowing for a 30 to 40% increase in stocking rates. The problems of turning out animals onto waterlogged land three weeks earlier than at present have not been assessed but this may place an important constraint on the utilization of the extra grass growth as climate changes (Armstrong and Castle, 1992)

The dynamic model

The Hurley pasture model of Thornley and Verberne (1989) is a process-based representation of the carbon and nitrogen pools and fluxes in grassland under grazing or cutting. It comprises three linked submodels; plant, soil and animal. The plant submodel is concerned with the growth of the grass crop and its physiological responses to environmental factors including temperature and CO_2. The soil submodel consists of soil carbon and nitrogen pools including dead and live organic matter. The model has been run by Thornley *et al* (1991) to simulate the response of grassland productivity and the carbon sequestration in soils under climate change scenarios of increased temperature and atmospheric CO_2 concentration. In this simulation the effect of variable CO_2 is through its direct influence on photosynthesis and subsequently on net primary production. Because of the slow turnover of soil organic matter in grassland (20-50 years) the model was run to simulate 50 years to ensure that the system was effectively at steady state (Thornley *et al,* 1991).

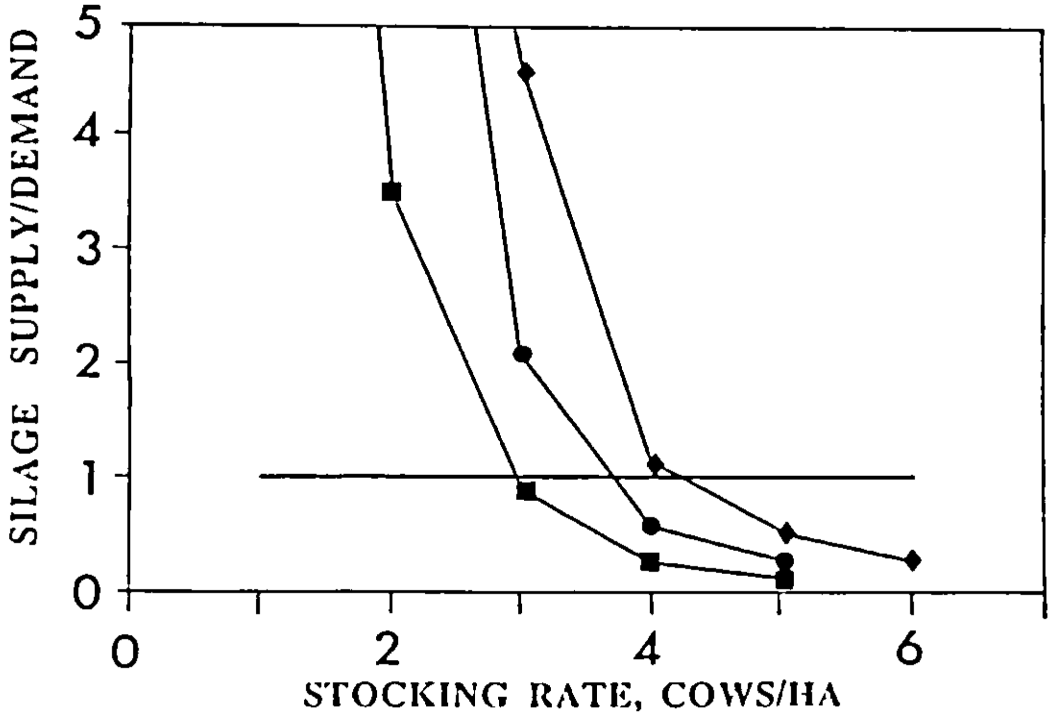

Figure 2: Optimisation of stocking rate for three climate scenarios: ■, present day; ●, mean temperature 2°C higher than present and +10% winter, -10% summer rainfall; ♦, CO_2 fertilizer effect in addition to temperature and rainfall change.

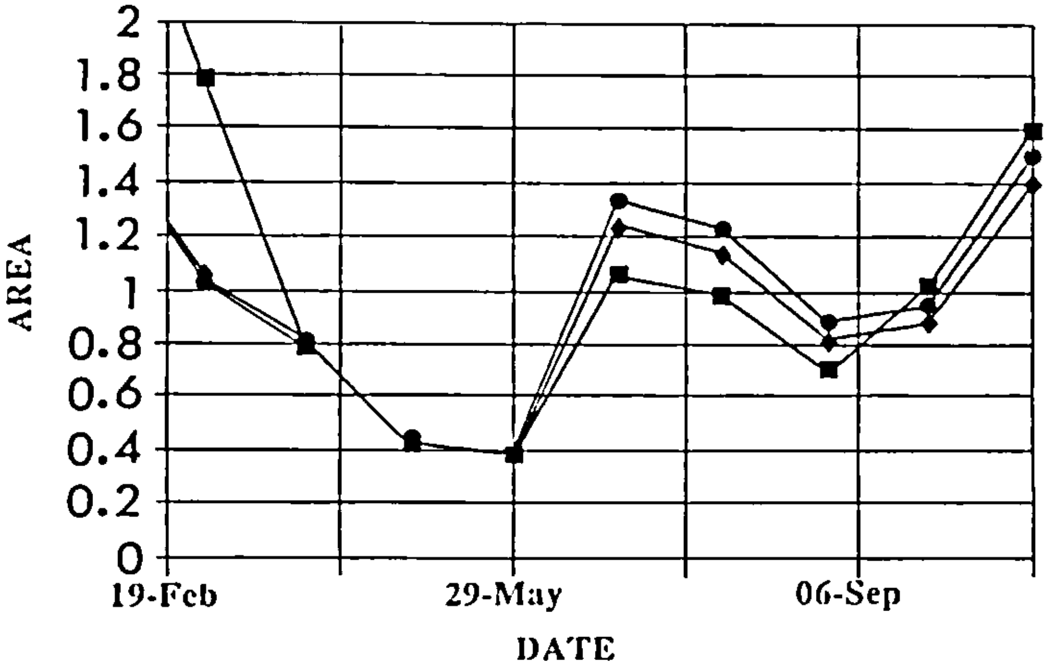

Figure 3: Fraction of farm area needed for grazing at the optimum stocking rate for three climate scenarios: ■, present day; ●, mean temperature 2°C higher than present and +10% winter, -10% summer rainfall; ♦, CO_2 fertilizer effect in addition to temperature and rainfall change.

Figure 4 shows the Hurley Model predictions of changes in grassland production and carbon sequestration in soils brought about by raising mean temperatures by 2°C from 14°C and increasing CO_2 concentrations from present day (350 ppmv) to 600 ppmv (Thornley, pers. comm.). Increasing temperature reduced production by a small amount but reduced carbon sequestration significantly. Both productivity and carbon sequestration were markedly stimulated by the increased CO_2 levels. These simulations on an extended time scale illustrate the importance of grassland as a carbon sink. At present grassland soils in Ireland contain about 5.3% carbon while tillage soils are about 3.4% carbon. The model output suggests that grasslands will become an increasingly important sink for CO_2. This could be significant on the global scale considering the importance of grassland vegetation generally. For example, it can be shown that in Ireland the predicted increased carbon sequestration with a rise in CO_2 from 350 to 600 ppmv could account for 30 years of the total carbon emissions from the island.

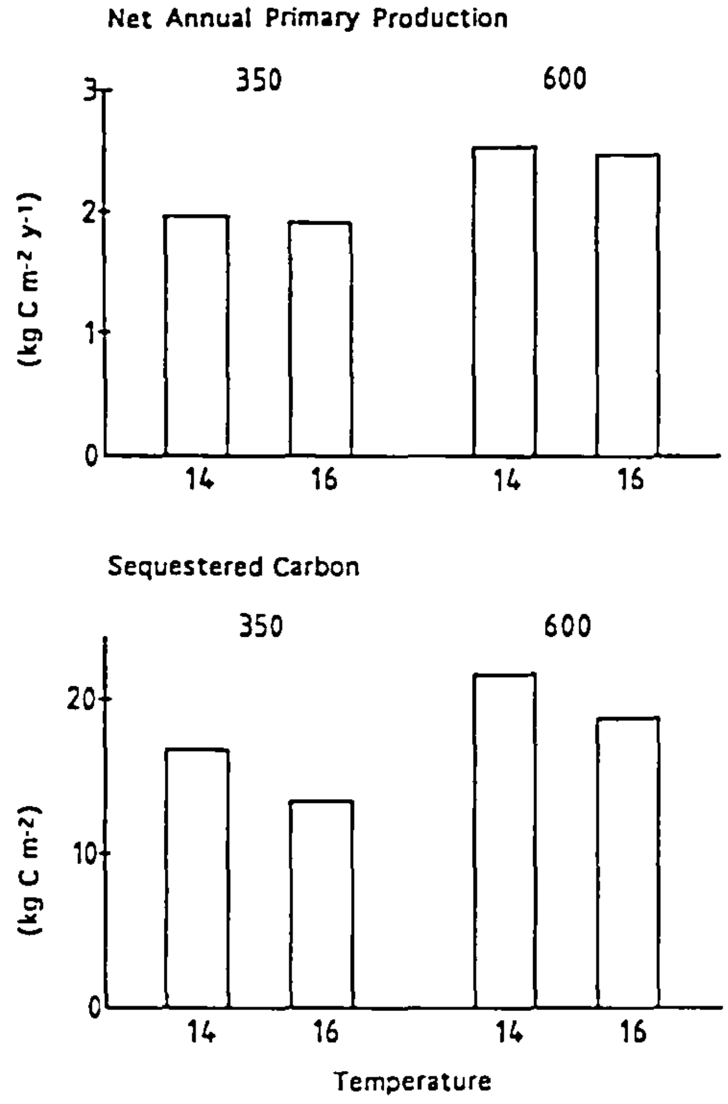

Figure 4: The predicted effect, using the Hurley Pasture Model, of a 2°C rise in mean temperature and an increase in atmospheric CO_2 concentration from 350 to 600 ppmv on (a) Net annual primary productivity, and (b) carbon sequestered in the soil (from Thornley et al., 1991).

CONCLUSIONS

The three different approaches adopted here to investigating the effects of climate change on grasslands should be seen as complementary. Model outputs require validation and the experimental and direct observational approaches should allow this. On the other hand, models can make predictions which are spatially and temporarily impossible with the two other approaches. It is hoped that the combination of these approaches can be used in an increasingly interactive manner to enable us to make more accurate predictions of the consequences of climate change for grasslands.

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THE POTENTIAL OF A CHANGING IRISH CLIMATE FOR EXISTING AND NEW CROPS - A COMPARATIVE ASSESSMENT

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SUMMARY

If the climate were to change along the lines predicted then it is possible that the agricultural production potential of Northern Europe could be enhanced over the next 40 years and Ireland would share in this advantage. The production options available would be increased, new crops could be cultivated and the overall costs of agricultural production would probably be less than at present.

There would, however, be little or no increase in cereal yields. Yields of other tillage crops like sugar beet and potatoes could increase by up to 20%, although there are many uncertainties about the possible effects of climate changes on these crops. Diseases, pests and weeds might pose a greater problem than at present. Arable crops currently grown predominantly in the south and midlands might find northern regions equally amenable in the new scenario; similarly the cultivation of a number of new crops - such as maize, sunflower and flax and other oil seed crops could become viable over much of the south and southeast. The regions suitable for early potato production could greatly increase.

Significant changes would be likely in horticulture. The cultivation of French beans, haricot beans, courgettes, summer cauliflower and celery could become more common, while apples, pears and cherries could be grown over wider areas than is currently the case. The successful harvesting of gooseberries and raspberries west of the Shannon would become possible. The production of grapes for dessert and for wine-making may also become feasible especially in the south and south east.

Changing climate is likely to have an enhancing effect on forestry, however, since the availability of both water and nitrogen are soil related, the regional effects of climate change on forestry will depend, inter alia, on the distribution of various soils over the national landscape.

The effect of future climate on forest diseases is uncertain. Some diseases could be expected to decline as they are favoured by cool, moist weather whereas others liking dry, warm conditions would become more common. Any future threat to Irish forests as a result of climate change is more likely to come from insects than from diseases. Climatic warming could also affect the movement within Europe and beyond of more exotic pests over and above those which currently affect our trees.

INTRODUCTION

The "greenhouse effect" is not a new discovery. It has been known for a long time that changes in the composition of the atmosphere may have an effect on the earth's radiation budget, thereby contributing to the rise or fall in the average temperature of our planet. It is only in the past two decades, however, that concern that human activities may play a key role in these processes has become widespread (McWilliams, 1991).

Two factors can explain the previous apathy. Firstly, the climatological data from 1940 to 1970 showed that the average global temperature was, if anything, falling slightly. Insofar as scientists worried at all about our future climate, their concern was that we might be descending slowly but inexorably into another Ice Age. The second factor was the dearth of data about the concentrations of carbon dioxide and other greenhouse gases in our atmosphere.

Developments occurred on both fronts. During the International Geophysical Year of 1957-1958 accurate measurements of the amount of CO_2 in the atmosphere were instituted - most notably at the Hawaiian Observatory of Mauna Loa. By the early 1970's the upward trend was indisputable, and we now know that in the 30 years or so since these measurements began the concentration of carbon dioxide in the air has increased from some 315 parts per million to 350 ppm - and is still rising.

The 1970's brought another disturbing trend. The fall in global temperatures reversed itself, and during the last two decades there appears to have been a slow but sustained increase in the average temperature of our atmosphere. As these trends continued into the eighties, fears about global warming were exacerbated by output from the newly available General Circulation Models; succeeding generations of these models varied considerably in the range of their predictions, but were virtually unanimous in the conclusion that anthropogenic greenhouse gas emissions would lead to significant global warming in the coming decades.

It must be emphasised again that various climatic change scenarios are not predictions, but are working assumptions on possible outcomes suggested by "state of the art" climate models and other observations. Further information from more sophisticated General Circulation Models may, in due course, render these assumptions invalid, but for the moment, they represent a "best guess" on which to assess the hypothetical impact of climatic change on Ireland.

The implications of the greenhouse effect on agricultural production is now the focus for serious discussion and research and this paper aims to assess the likely implication for tillage, horticultural and forestry crops in Ireland.

1. Tillage Crops

There are several components of the weather which affect crop growth and development but the most important to date - if we exclude pests and diseases - are solar radiation, temperature and rainfall. In the absence of other limiting factors, temperature determines the length of the growing season in cooler climate regions like Ireland, principally by its effects on the timing of developmental processes and on rates of expansion of leaves.

Most processes of development and expansion (e.g. leaf expansion, flowering, grain filling) can be described by a linear increase of rate with temperature from a minimum temperature limit (Monteith, 1981)

1.1 Direct effect of carbon dioxide and other gases on crop growth

The greenhouse effect is a complex phenomenon involving carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_20), tropospheric ozone (O_3) and some chlorofluorocarbons (CFC's) and their interaction with elevated temperature, rainfall patterns and crop growth. While all of these substances are important, carbon dioxide is the main driving force for photosynthesis and has been studied by many research workers. To date most of the research has been carried out in controlled environment chambers and this work has shown that elevated carbon dioxide levels increase crop growth rate. For this reason carbon dioxide enrichment is widely employed in glasshouses to raise yield of crops such as tomatoes, lettuce, cucumbers and flowers (Enoch and Kimball, 1986). However, crop species vary in their response to elevated carbon dioxide; for example, the so-called C4 plants (maize, sugar cane, sorghum) are the least responsive, compared to C3 plants (wheat, barley, sugar beet, potato and grasses) which respond well (Goudriaan & Ruiter, 1983). A review of Kimball (1983) showed that a doubling of carbon dioxide increased mean dry matter yield by 15% for C4 plants and by 40% in C3 plants.

Whether these effects would be carried over into crops growing in the field is not yet clear. Increased carbon dioxide levels also improve the plants' water use efficiency which will help to offset part of any reduction in rainfall that might occur. The effect of elevated carbon dioxide alone on crop growth rate in Ireland is likely to be positive in the long term, with current species increasing in final yield by up to 25%.

1.2 Effects of elevated temperature

In order to determine the effect of elevated temperatures on crop growth and yield, use has been made of crop growth models at Oak Park Research Centre to make some predictions (Burke and McGuinness, 1988). These models attempt to take account of the interaction of climatic conditions and physiological mechanisms in what is sometimes referred to as a mechanistic approach. They assume the crop is adequately supplied with nutrients and water and is free from all pests and diseases.

The studies carried out on cereals, sugar beet and potato crops are discussed in that order and, as they exclude the carbon dioxide element, initially they should be considered as "worst case" scenarios.

Cereals

The effect of elevated temperatures on cereal crops can be seen from studies carried out on winter wheat at Carlow (Figure 1). The modelling study showed that the duration of full canopy decreased (Figure 2) resulting in reduced radiation interception and lower potential grain yield.

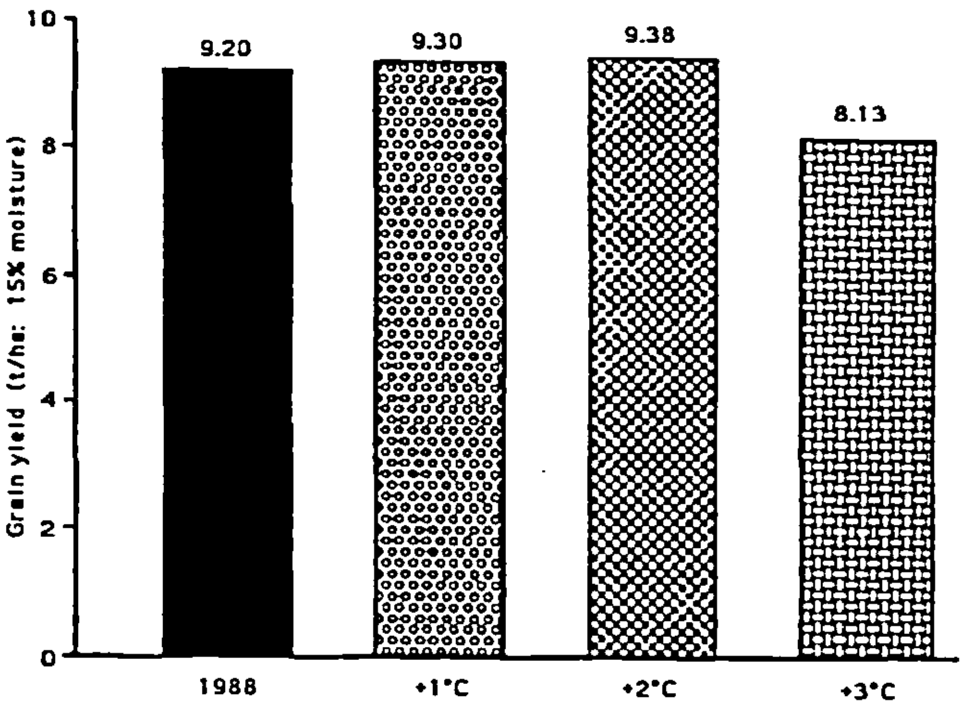

Figure 1: Winter wheat grain yields as influenced by increased temperature

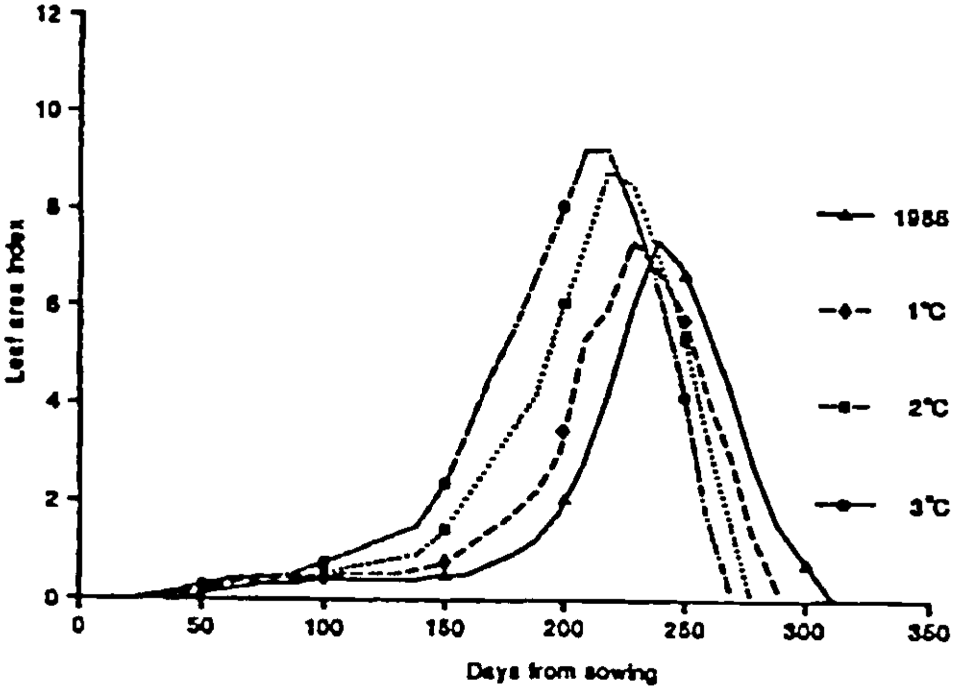

Figure 2: The effect of higher temperatures on leaf area development

The modelling study to date indicates that the partitioning of assimilates, *i.e.*of both carbon and nitrogen, is significantly influenced by increased temperatures, resulting in reduced harvest index values (Table 1). Rate of development, and thus the duration of the vegetative phase of cereal crops during which photosynthetic production capacity is determined, is a linear function of temperature and photoperiod and will therefore be reduced as temperature increases.

Table 1: Effect of climate change on crop yields

	Scenario			
Crop	A	B	C	D
Winter Wheat				
Total Dry Matter t/ha	18.91	23.63	25.52	23.25
Grain yield (t/ha)	9.20	9.45	9.44	11.16
Harvest index (%)	49.00	40.00	37.00	48.00
Sugar Beet				
Root fresh weight (t/ha)	70.00	77.00	88.00	86.00
Potatoes				
Tuber yield (t/ha)	61.00	65.00	84.00	78.00

Scenarios

A = Simulated crop yield using 1986 weather data at Oak Park Research Centre
B = 430 ppmv CO_2 and a 2°C temperature rise coupled with a 10% increase in winter precipitation and a coreesponding decrease in summer values.
C = 430 ppmv CO_2 and 3°C temperature rise with a 15% increase on average rainfall.
D = 430 ppmv CO_2 and a 1°C temperature rise with little change in precipitation.

Spring cereals will follow a similar pattern but will have an extended potential growing season coupled with a shorter esimated maturation period which may vary from 7 to 21 days. It is also possible that there would be a movement of cereal growing to the east midlands from the south and southeast.

Sugar Beet

Unlike cereals sugar beet - being an indeterminate crop - continues to grow within the vegetative stage and produces yield, provided that the temperature is above the minimum threshold. Assuming therefore that water is not limiting, the computer modelling studies carried out on sugar beet crops at Oak Park Research Centre calculated that sugar beet yield could rise by up to 20% (Figure 3). The calculation is based on earlier and faster leaf growth, and by earlier canopy closure and thus greater radiation interception.

This will have many implications for the Irish sugar industry, since production here is linked to EC quotas and consequently, if sugar beet yields rise, more land will have to be taken out of sugar beet production. Also the introduction of autumn/winter sowing instead of mid-March currently practised may become possible, and this would have major implications for the commencement time and duration of the harvesting campaign. Reduction in summer rainfall of 10% would reduce yield and the areas of production may move to the midland regions unless irrigation facilities are provided. Factors such as soil type, farm size and farming practice will, however, restrict the options in this regard.

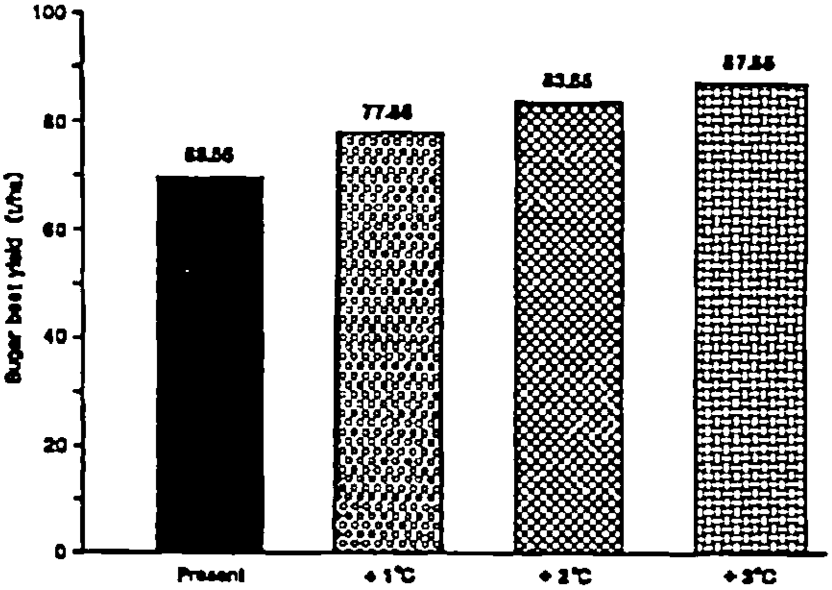

Figure 3: Effect of temperature rise on sugar beet yields in Ireland

Potatoes

As with sugar beet, the yield of potato crops is likely to increase (Figure 4) as temperatures rise. Where water availability becomes limiting, the increase may be partially offset and irrigation may be required to realise the full yield potential. Also high temperatures, especially coupled with water deficit, induces secondary growth affecting quality and marketable yield.

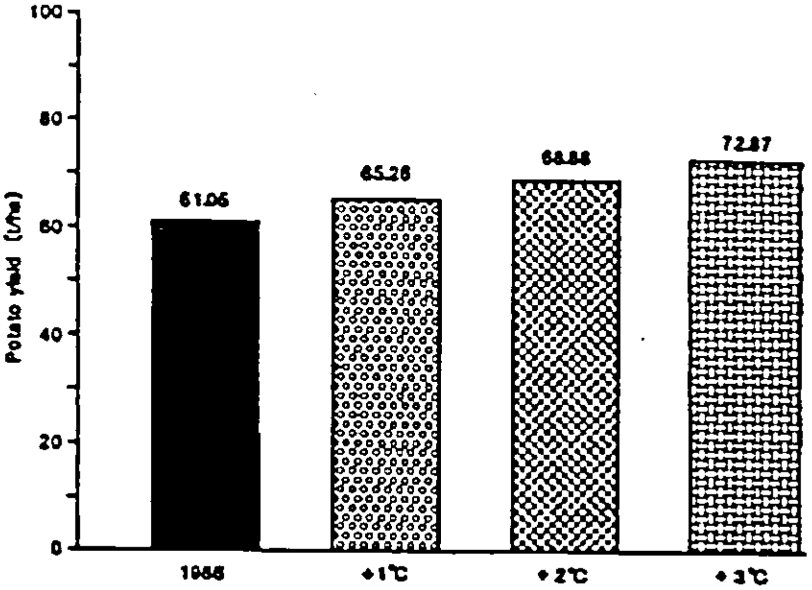

Figure 4. Potential potato yield for 1^oC, 2^oC and 3^oC increases in temperature, Carlow, 1986

Alternative crops

While much encouragement is given in the EC at present to the development and growth of new crops for oil, protein and fibre, the opportunities so far for Irish farmers are limited, largely because of the unfavourable climate. However, changes in temperature could lead to large acreages of maize, dwarf sunflowers and vines being grown in the south of Ireland.

Possibilities for growing maize for grain, as well as for forage, would increase significantly. Previous studies carried out on forage maize in Ireland showed that low temperature was the major factor limiting dry matter production per hectare. Higher temperatures would facilitate earlier sowing and increased dry matter production per unit area, mainly through greater grain production.

In addition crops like oilseed rape, linseed and flax already grown in the main tillage areas could yield significantly better in warmer climates. (Goudriaan and Bijlsma, 1987)

Oilseed rape has been one of the most successful of the oil crops evaluated to date and is tolerant of the low light intensity, low summer temperatures and high rainfall in Ireland. It is used for the production of vegetable oil and the yield obtained varied from 2-4 tonnes seed/ha. This yield compares favourably with those obtained in the United Kingdom and in other EC countries. Oilseed rape, however, is most usually sown in autumn, and the high winter rainfall which might accompany global warming may make the heavier soils more unsuitable for the production of this crop while higher spring temperatures could make spring sowing of oilseed rape a more attractive proposition.

1.3 Interaction of elevated carbon dioxide and increased temperature

The effect of elevated carbon dioxide concentrations coupled with an increase in annual mean temperature is more likely to be positive, with current arable crops increasing in yield (Table 1). Cereal crops may not be as responsive as crops like sugar beet, potatoes and other root crops due to changes in harvest index values for cereals.

1.4 Weeds

At the time of writing, there is no definite information on the implications of global warming for weeds, diseases and pests for Ireland. However, we can speculate that warmer winters would extend the growing season of some mature weeds and many weed species which currently flourish in warmer climates could become a greater problem here. Also, other more drought resistant weeds could increase and be more difficult to control. Changes in weed leaf growth, particularly with regard to cuticle waxes, may reduce the efficiency of current herbicides. Weed competition is therefore likely to increase due to their greater ability to respond to climatic change.

1.5 Crop diseases

Cereals

An increase in average annual temperature of the order of 2°C would not have a large impact on cereal diseases. The diseases that affect cereals in Ireland are common to cereal growing areas in warmer climates such as the south of France and Spain. Brown rust may increase as it is a disease that is favoured by warm conditions and usually does not occur here until later in the season *i.e.* July/August. Mildew would become more prevalent.

A change in precipitation patterns would have a greater impact. Wetter winters could mean more take-all as wet warm soils tend to favour take-all development over the winter. (This would only apply to autumn sown crops). Wetter winters could also lead to a higher incidence of autumn/early spring eyespot infection.

Drier springs and summers would tend to favour fusarium root rot, as this disease is much more prevalent in dry springs. It is a major problem in the drier wheat growing areas of the world and is difficult to control as there are no effective chemicals.

Brown rust and mildew would also tend to increase, but splash dispersed diseases such as septoria, rhynchosporium and net blotch would decrease.

A temperature increase of 3°C coupled with a precipitation increase of 15%, would cause diseases like *Septoria nodorum* and ear fusarium to become major pathogens, while mildew would be less of a problem.

Sugar Beet

In the case of sugar beet it is likely that we can expect increased problems caused by indigenous pests and diseases. In addition, pests that are currently prevalent in southern Europe such as tortoise beetles, caterpillars of various moths, fleas, beetles and cutworms could increase in importance.

Beet cyst eelworm currently in Ireland could spread more quickly. Increased temperatures would also favour the overwintering of soil pests and pathogens and their multiplication in the spring.

The introduction and spread of the devastating disease Rhizomania is also a possibility and this could have serious implications for sugar beet growing. Foliar diseases such as cercospora leaf spot, leaf rusts as well as virus yellows could also become more common.

Potatoes

The effect of global warming on the major potato diseases and pests is given in Table 2. From a national viewpoint, the most important effects would be to increase the aphid-transmitted virus diseases together with common scab, early blight, dry rot and drought stress. A decrease in powdery scab, late blight, gangrene and stem canker may counterbalance the above. Increased temperatures could also lead to the introduction of problems such as Colorado beetle, vascular wilts and potato tuber moth which have so far been excluded from Ireland. It is postulated therefore that some of the benefits of warmer and drier growing seasons in Ireland may be offset by increased loss from weeds, pests and diseases.

Table 2: Predicted effect of climate change on the incidence of different potato diseases and pests in Ireland.

Increase	No Change	Decrease
Potato Virus Y	Potato Virus X	Potato Mosaic Top Virus
Potato Leaf Roll Virus	Potato Virus S	Powdery Scab
Common Scab	Skin Spot	Late Blight
Early Blight	Silver Scurf	Gangrene
Dry Rot	Cyst Eelworm	Stem Canker
Verticillium	Black Scurf	Wart Disease
Fusarium Wilt		Frost Damage
Colorado Beetle		Spraing
Soft Rot		
Aphids		
Tuber moth		
Drought Stress		

2. Horticultural Crops

Most crops including vegetables give the largest yields and the highest quality under conditions of high light intensity, high temperature and low rainfall (Wilsie, 1962). The drier, sunnier parts of the United Kingdom are most suitable for the production of peas. French beans are subtropical in origin and require a soil temperature of above 18°C for germination (Bland, 1971). Carrots and onions produce the highest yields and the best quality in the more dry, sunny and warm parts of the temperate zone. Celery, cauliflower and cabbage also benefit from high temperature and high light intensity. Beet requires high soil moisture and therefore benefits from high rainfall. Many of the celery and cauliflower cultivars are intolerant of sub-zero temperatures. The most common self-blanching celery cultivar, Lathom Self Blancing, must be harvested before mid-November or it is likely to be killed by frost.

The common top fruits also require a high temperature, adequate sunshine and low rainfall. Apples, pears, cherries and plums yield best at a rainfall of from 625-875 mm. Cherries, plums and pears are early flowering and are sensitive to April and May frosts. High rainfall increases the incidence of scab and canker in pears and applies (Bush, 1962). Among the bush fruits, frost damage is common in blackcurrants, particularly the early flowering cultivars. Redcurrants require well drained soils. On the other hand, gooseberries prefer moderate temperatures and are suited to the Irish climate. Raspberries require high soil moisture and due to their later flowering period are not very often affected by spring frost. High light intensity is not required for raspberry production. Strawberries, like blackcurrants can be damaged by late spring frosts and thrive under high light intensity and high temperature. The climatic preferences of the various vegetable and fruit crops are summarised in Table 3.

Table 3: **Climatic requirements for production of vegetable and fruit crops**

Crop	Temperature (summer)		Sunshine hours (per day)		Rainfall (per year)	
	<15°C	>15°C	<3.5	> 3.5	<750 mm	>750 mm
Broad beans		X	X			X
French beans		X		X	X	
Beetroot	X		X			X
Cabbage	X		X			X
Carrots		X		X	X	
Summer cauliflower		X		X		X
Celery		X		X		X
Peas		X		X	X	
Early potatoes		X		X		X
Onions		X		X	X	
Apple		X		X	X	
Pear		X		X	X	
Cherry		X		X	X	
Plum		X		X	X	
Blackcurrant		X		X		X
Gooseberry	X		X			X
Redcurrant		X		X	X	
Raspberry	X		X			X
Strawberry		X		X	X	

Present temperature and rainfall data were modified to take account of an increase of 2°C in temperature and a ± 10% change in rainfall (Figures 5, 6 and 7) in order to assist in the evaluation of the performance of different crops over their full growth season. For example, a soil temperature of greater than 10°C is required for the germination and growth of most crops. A 2°C increase will increase the temperature from above 8°C to above 10°C south of a line from Clifden, Co. Galway to Newbridge, Co. Kildare and northwards to Carlingford, Co. Louth. Furthermore, during the February to May period there is a temperature increase of approximately 2°C/month (Meteorological Service, 1984) so that a 2°C increase for any one month gives an advance of one month in plant growth. The mean temperature decreases by approximately 3-5°C from October to November so that a 2°C increase in November will also extend the growing season by about 17 days. Consequently a 2°C increase in temperature will increase the growing season for vegetables by approximately 48 days.

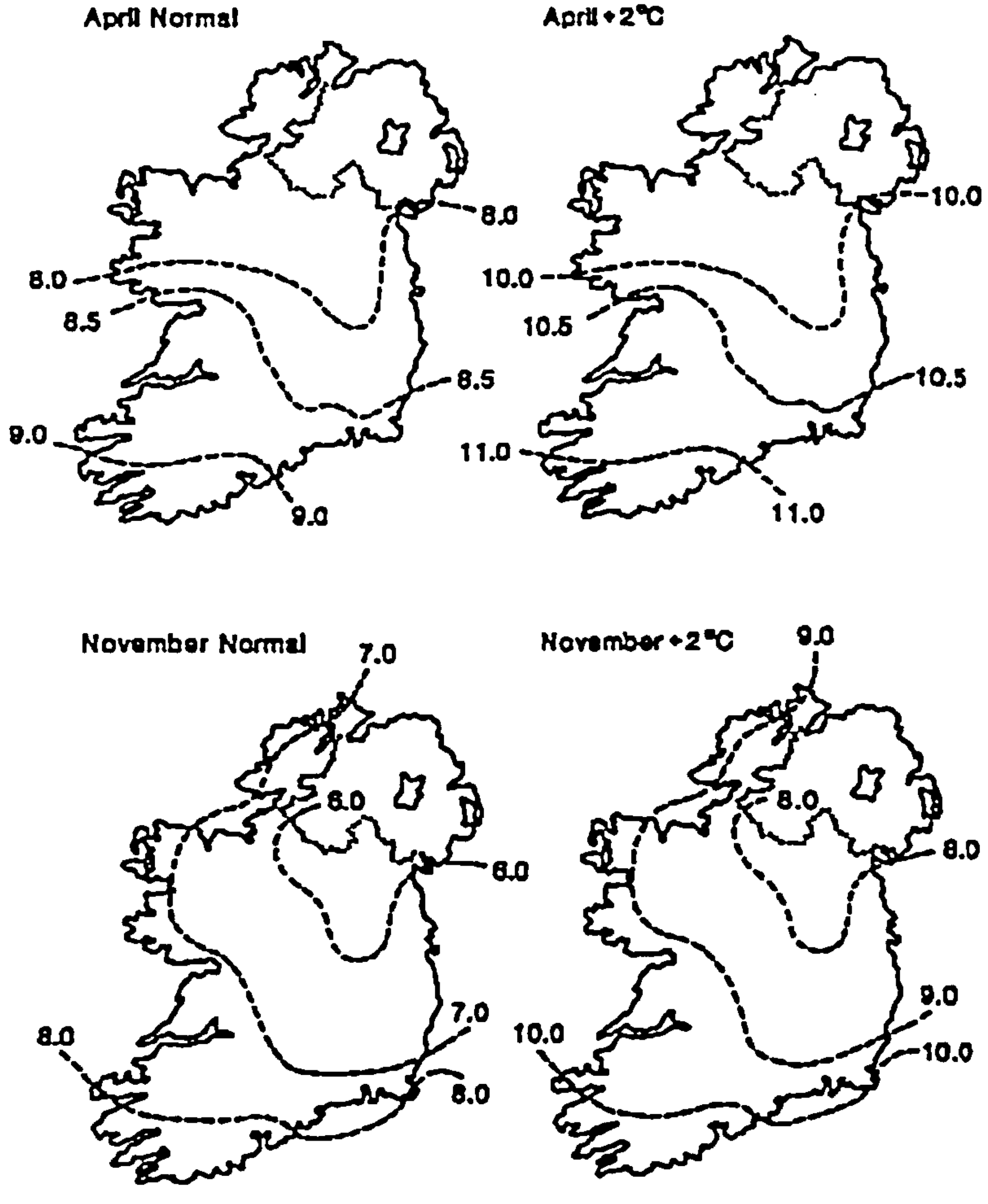

Figure 5. Northward displacement of isopleths of temperature as a result of a 2°C rise in temperature in April (top) and in Nov (bottom), based on mean values 1951-1980

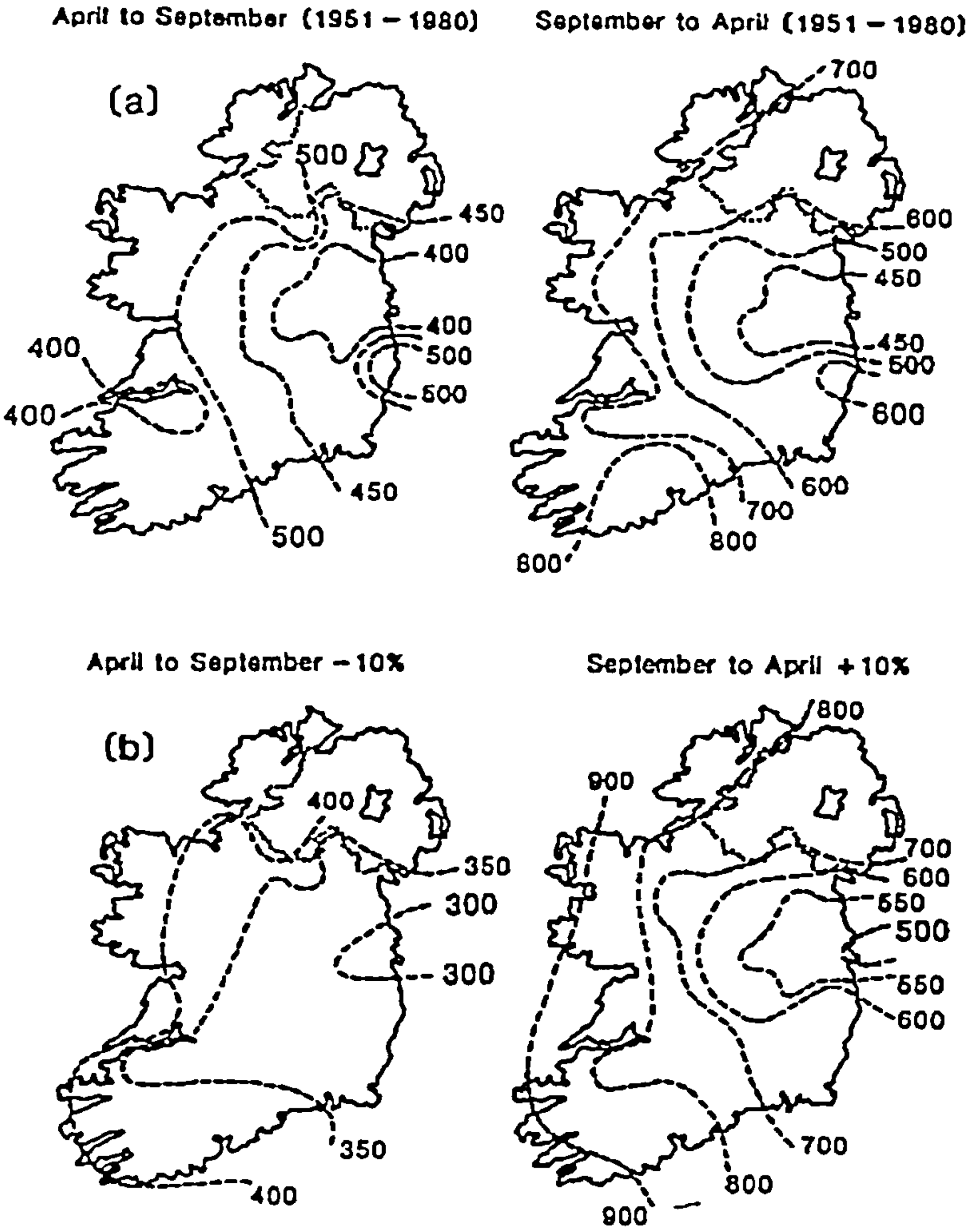

Figure 6. Displacement of isopleths of rainfall (in mm) from (a) the normal summer and winter pattern, following (b) 10% decrease in summer and 10% increase in winter

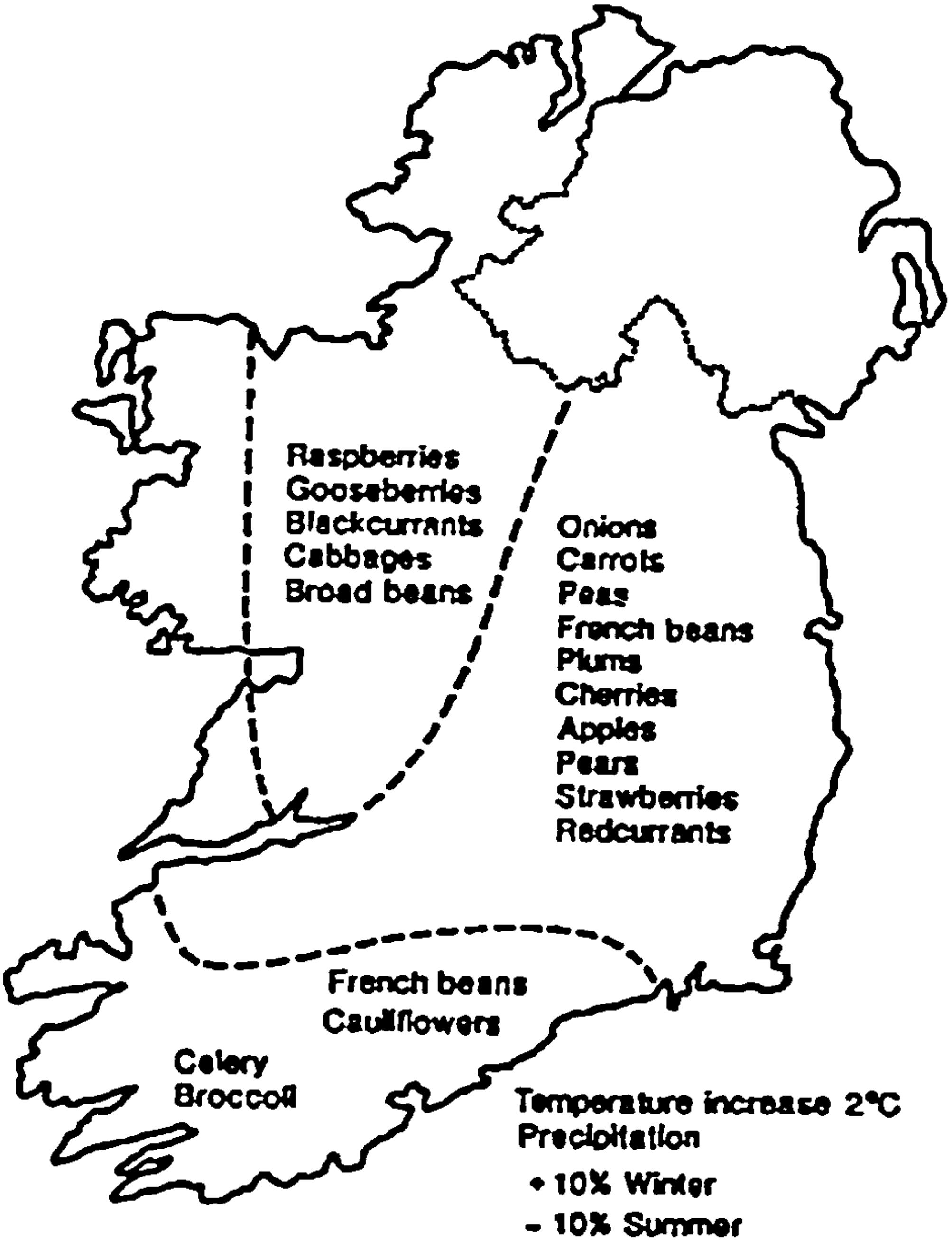

Figure 7 Climatically suitable areas for the production of fruit and vegetables under the conditions of global climate change indicated

2.1 Vegetables

The high June to August temperature, the extended growing season and the lower summer rainfall will have a significantly beneficial effect on fruit and vegetable production in Ireland.

At present the Irish climate is considered to be marginal for the production of such vegetable crops as French beans, carrots, peas and onions. The commercial production of French beans is not recommended. Onions, carrots and peas can be grown successfully but in wet seasons the keeping quality and skin colour of onions is adversely affected and crop failures are likely to occur on heavy soils. The smoothness and regularity of carrot roots are disimproved in cold, wet seasons. Continuous haulm growth in pea crops causes the peas to ripen unevenly and gives rise to problems with harvesting. These problems are least obvious although not entirely absent along the east and south-east coasts where temperatures are highest and rainfall is lowest.

The projected temperature increase and summer rainfall decrease will make the areas east of the river Shannon suitable for the production of French beans, haricot beans and hops. Courgettes, squash and sweetcorn will also grow successfully. These require a temperature of 16°C for germination and may be sown in late May or early June (Anon. 1980). Production of these crops will not be possible on elevated ground as growing conditions disimprove considerably and the length of growing season is shortened with a rise in altitude (McEntee, 1978).

Summer cauliflower, summer broccoli, celery and early potatoes all require high temperature, high light intensity and high rainfall. With the climatic changes projected these crops will be more suited to areas of "good" soil west of the R. Shannon (Figure 8).

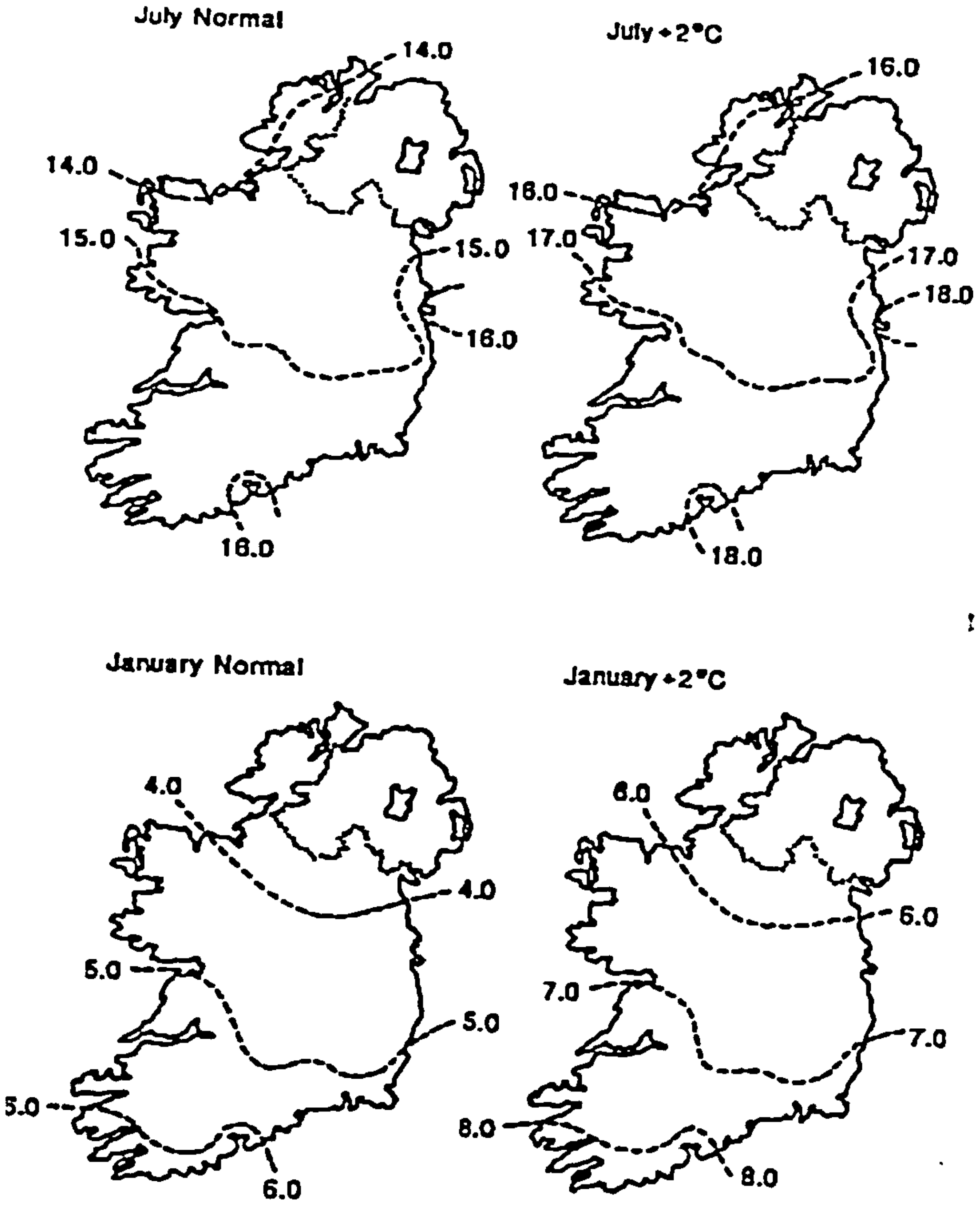

Figure 8 Northward displacement of isopleths of temperature following a 2^{o}C rise in July temperature (top) and in January (bottom). Based on mean values for 1951-1980

2.2 Top fruit

Apples are the only top fruits which are suitable for production in the present Irish climate. The dessert cultivars require moderate rainfall and well drained, deep, slightly acidic soils. For these reasons apples are grown mainly on the acid brown earth soils in the south east. Apple scab and canker are serious problems in high rainfall areas and in heavy soils. A decrease in rainfall and an increase in temperature will make the production of apples possible in more northerly areas. Such high quality cultivars as Cox's Orange Pippin and Golden Delicious would grow more successfully in Ireland with a 2°C increase in temperature and a decrease in summer rainfall.

Cherries, plums and pears are not suitable for commercial production in Ireland at present. These top fruits flower in April and May. Frequent frosts occur during these months in Ireland and the newly set fruit abort when exposed to sub-zero temperatures. Cherries in particular require low rainfall and dry soil. The increase in temperature as a result of global warming will eliminate frost damage in pears, cherries and plums in April and May in most parts of the country. Lullymore in Co. Kildare was the location with the lowest mean temperature during the 1951-1980 period (Meteorological Service, 1984). A study of the meteorological records for this station between 1968 and 1981 shows that the number of sub-zero temperatures per annum recorded within the screen was 6.3. Assuming a 2°C rise in temperature only four killing frosts (less than 2.2°C) would occur during April in this 19 year period, two in 1966 (-4.2°C, -5.5°C), one in 1973 (-2.5°C) and one in 1976 (-2.5°C). In other parts of the country the only killing frost likely to affect fruit set in pear, plum and cherry would be that in 1966 and this damage would have occurred only in the north Kildare-Offaly area.

2.3 Soft Fruit

Of the soft fruits, gooseberries grow most successfully in the present Irish climate, doing equally well in high rainfall and low rainfall areas. High temperatures are detrimental but hard spring frosts may reduce fruit set. With the 2°C rise in temperature and the 10% reduction in summer rainfall, gooseberries will grow very successfully west of the Shannon. The temperature for successful growth in south Munster is likely to be too high.

Raspberries are also suitable for the Irish climate. The natural habitat of the raspberry is semi-open woodland. The cultivated raspberry requires a good sheltered location, high soil organic matter and high soil moisture. It is not well adapted to high light intensity and high temperature. With a rise in temperature and a decrease in summer rainfall this soft fruit will grow most successfully in east Connaught in deep, moisture retentive soils. Blackcurrants also require high soil moisture but in the present climate blackcurrants, in particular the early flowering cultivars, are subject to frost damage in spring. A 2°C rise in temperature will favour the growth of this fruit because it will reduce the risk of frost during this period. Blackcurrants are more likely to succeed in the higher rainfall areas of south Munster with the onset of global warming but will grow quite well in other parts of the country also.

The strawberry requires high sunlight, high temperature and a deep slightly acid soil with a high organic matter content. Freedom from spring frosts is essential for successful production and warm temperatures ensure early maturity of the fruit. At present strawberries are grown in the south east. An increase in temperature and a reduction in rainfall would make production of this fruit possible in more northerly areas. The redcurrant requires conditions similar to those for strawberries but favours slightly drier soil conditions. It will respond in a similar manner to an increase in temperature and a decrease in summer rainfall.

2.4 Vines

Under present climatic conditions the production of grapes is possible in the south of the United Kingdom. Vines normally begin to produce leaves in May and are not therefore damaged by late frost. Most cultivars require high light intensity, high temperature and low rainfall. Many new cultivars are bred to produce high quality fruit at lower temperature and light intensities. With an incrase in temperature of 2°C and a decrease in summer rainfall it is likely that the production of grapes for dessert and for wine making will become feasible especially in the south and south east.

2.5 Protected crops

The protected crops industry in Ireland is small compared with other EC countries (less than 750 ha) and its expansion is limited by the cost of supplementary heating. A rise of 2°C would reduce these heating costs and thus encourage some growth within the industry. On the other hand, an increase in cloud cover would result in reduced productivity under glass and polythene. Some crops which are at present grown under glass should be produced out of doors.

2.6 Potential under other scenarios

The effect of a 1°C rise in average temperature will make the climate in Ireland more suitable for the production of onions, carrots, summer cauliflower, celery, peas, apples and strawberries. There is likely to be a small and gradual increase in the area under these horticultural crops. The area under maize is also likely to increase. It is unlikely that there will be any increase in the area under oil crops or vines as a result of a 1°C increase in temperature.

The effect of a 3°C increase in temperature and a 15% increase in precipitation on rainfall distribution and on temperatures throughout the country is shown is Figure 9. These temperatures and precipitation increases are likely to decrease the area under most vegetable and fruit crops. High rainfall is undesirable for such crops as onions, carrots, french beans and peas and for fruits such as apples, pears, plums, cherries and strawberries. The area under brassica crops, celery, blackcurrants and raspberries may increase. The production of courgettes, melons and peppermint may also increase. High soil moisture and high temperatures favour the production of these crops.

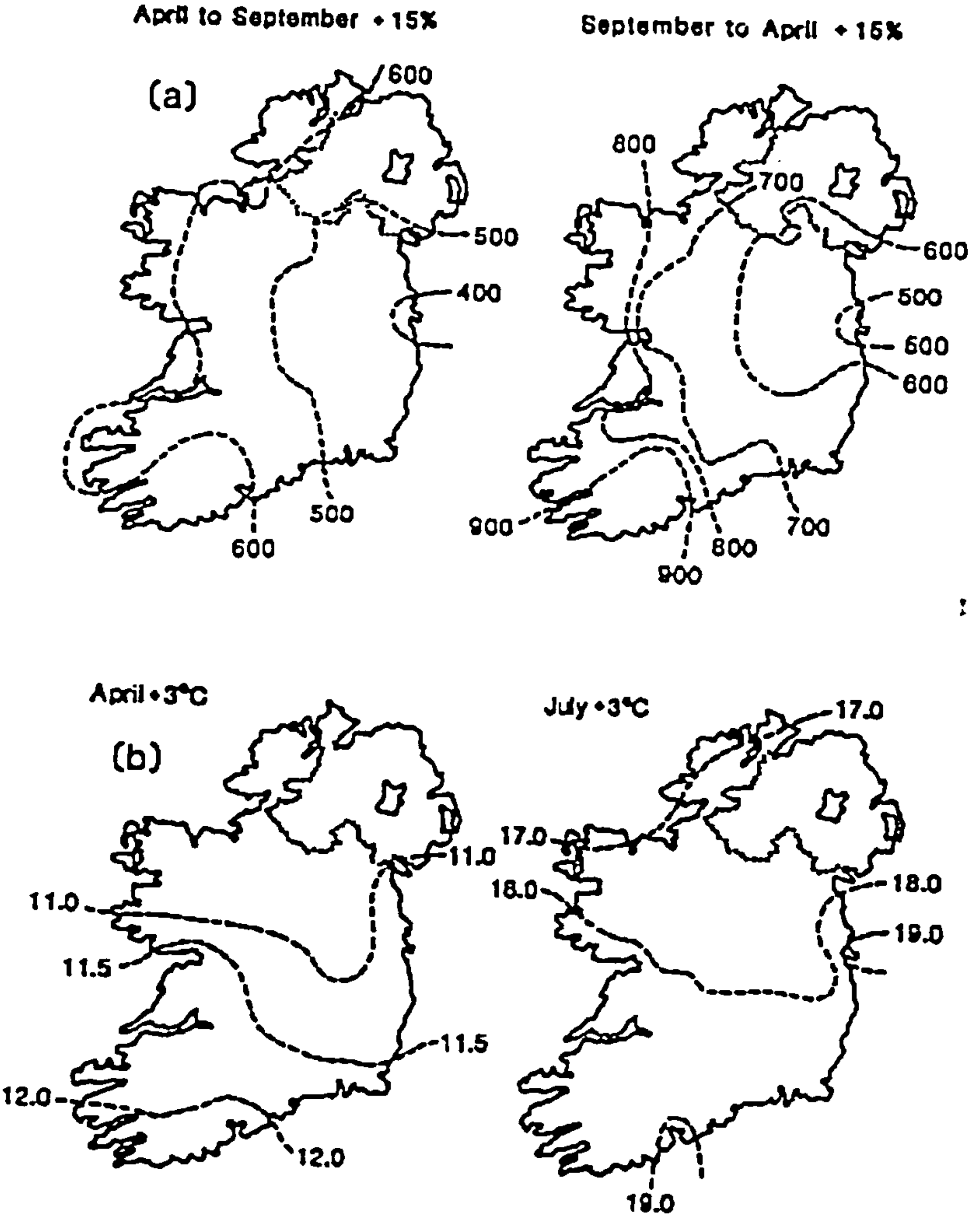

Figure 9 (a)Displacement of isopleths of rainfall (in mm) following a 15% increase in summer/winter precipitation, and (b) a 3°C increase in temperatures in Ireland (based on mean values 1951-1980)

3. Forestry

The longevity of trees and forest crops makes them of particular use in tracing past evidence of climatic change. It is also this longevity, however, that makes forests more vulnerable to future change.

Trees and forests, therefore, may be more affected than other plant species by changes in climate. Trees are especially vulnerable to extreme events such as frosts, gales or droughts as the latter two particularly may destroy biomass that has built up over many years.

3.1 Assessing the impact of climatic change on Irish forests and the forest industry.

The Problems

We have seen already how unpredictable projections of future climate might be. Even if we could be more sure, forest biologists are far from being in a position of confidence to predict the individual tree or forest response.

The potential problems in this regard can be summarised as follows (Eamus and Jarvis, 1989):

1. Few experiments in this area have lasted more than two years and hardly any have considered the potential effects from nutrient stress in a natural environment or of variation in soil type.

2. We simply do not yet understand the possible implications of climate change on within-tree biomass allocation.

3. Because of their size, it is difficult if not impossible to predict how trees or forests will respond in comparison to seedlings.

Given this enormous uncertainty, what can foresters now do to prepare for the threats and opportunities that the future might bring? The following might be considered.

3.2 Effects of climatic change on the choice of seed origins for our commonly grown forest trees

From information collected and observations made on established field trials over the years, Irish foresters now know the seed origins that suit our climates best. These selections, however, may now have to be reassessed in the light of suggested climatic changes and the effect of such change on the nature and scope of present tree improvement programmes is uncertain (Woodman, 1987; Cannell *et al.*, 1989).

Are to-days tree breeders working on material that will be suitable for tomorrows forests or on material that will grow hopefully in a climate similar to that of today? Much of the seed for future forests in fact will come from seed orchards selected for their performance over the past decades.

3.3 Choice of species

Choice of species is often the decision that first comes to mind when climatic change is suggested. Species changes may require, some proof that the productivities of species currently in use are threatened as a result of climatic change.

The sites were the maximum productivities for Sitka spruce, our most commonly planted conifer, are currently achieved on wet mineral lowland soils of moderate fertility where climatic conditions such as high rainfall, high humidity and moderate annual ranges of temperature occur i.e. conditions not dissimilar to its native habitat. Photosynthesis of Sitka spruce is much reduced in dry air as a result of stomatal closure and its productivity into the future maybe reduced in some eastern and southeastern localities.

Whether it increases its productivity in the wetter areas depends on other factors. For example, if chilling requirements are not fully met, then it may flush late and fail to exploit the longer growing season.

Other tree species adapted to milder areas, such as Monterey pine, Monterey cypress and some eucalypti, are able to grow almost continuously in milder parts of this country. Although such species have been damaged by frost in the past, the suggested warming may mean that their role in the future of Irish forestry may become more important.

The selection of any one species will not only depend on projected shifts in climate and resultant effects on productivities. It is also influenced by the predicted demand for products manufactured from the woods of this species.

In Ireland other factors will also influence the choice of species that is planted. The level of European Community grant-aid for private planting already differentiates between broadleaf and conifer planting and the European Community and the National Government may further influence the species that foresters plant in the future (Molloy, 1991).

In selection of species for afforestation or reforestation, therefore, many factors besides the influence of future climate will have to be taken into a account.

3.4 Silvicultural inputs

In the past, tree survival of planted trees has generally been high, particularly on afforestation sites. Future projected moisture stress in the mid-to-late summer may require change in site cultivation techniques or planting methods to lessen the impact.

Similarly, because of the reduction in the chilling period as a result of milder winters, certain species such as Douglas fir or noble fir may require additional investments in cold-storage facilities at the nursery stage because most of our nurseries are currently located in the south-east of the country and may not receive sufficient chilling in future winters.

Silvicultural decisions may also have to be reassessed later in the life of the crop. Stands may have to have rotation length changed or may require more or fewer inputs in fertilisation, pest management, *etc.*

3.5 The forest industry

Authors argue as to the absolute or relative importance of climatic change on forestry and the forest industry (Eamus and Jarvis, 1989; Hoffman, 1984).
Unfortunately, it is far too soon to be able to predict the biological or economic effects of global warming on forests or the forest products industry either here or in other countries. The changes will not happen overnight. The industry, therefore, has time to plan a strategic response through the methods outlined above.

The Industry must also examine the anticipated response to climate change from other sectors which impinge on it. In Ireland, these sectors might include the agricultural and energy industries. If climate change is to substantially influence either of these, then forestry will not be unaffected.

Much of the discussion in this paper is of relevance not only to Ireland but to all the wood producing nations in the world. Climate change is a global issue and will therefore influence world supply and demand for wood and wood products and therefore prices and profitability.

For a small trading nation such as Ireland, we must not forget that whatever strategies are decided upon in relation to climatic change and the forest industry, they must take into account the global picture of wood supply and demand. How well forest managers anticipate and respond to the anticipated changes in climate will depend on the climatic, biological, social and economic factors that have been touched on in this review.

In bringing these together, the most important considerations may be:

(i) Climatic models
Any form of planning requires forecasts of eventual outcomes. Our current climatic models need to be more precise, particularly in projecting regional climates, before responses can be planned.

(ii) Predicting growth responses
The responses of individual plants to increases in CO_2 concentration have generally been established and are quite well understood. The extrapolation of these results to the tree or forest level needs to be carried out, probably through the use of biological models. Further work is also required on the chilling requirements of our most common tree species (Leverenz and Lev, 1987).

(iii) New genetic needs
It is generally felt that productivities will increase in temperature plantation forests. Can species and populations be bred to anticipate the climatic changes and produce faster growing better quality timber under the new conditions?

If climatic conditions do change on specific sites, foresters may have to use alternate species rather than look to other seed origins of the existing species.

(iv) Planting and management

Foresters and forest planners must become more aware of future climatic trends as models improve. Only then will they be in a position to manage the risks and opportunities through manipulation of silvicultural practices. As forests move to better soils in the future, the choice of species will increase, even in the absence of climatic change.

(v) Hazards

Little precise information is available on how storm patterns will behave in our future climate. We can only anticipate the worst through proper cultivation and planting techniques, choice of species and thinning methods.

Sitka spruce may suffer large losses of increment through aphid attacks, particularly on dry sites. We must also maintain vigilance against exotic pests - many of which would enjoy a warmer climate here.

(vi) The forest industry

Decisions here will not be taken in isolation. The availability of land for Ireland's major planting targets of the future is dependent on European Community and National Government policies. How global warming affects agriculture and energy will also influence the forest industry.

(vii) The global scene

The future trends in climate change are world-wide. In Ireland, anticipated changes in productivities, markets and income depend also on the response of world governments and world industry to our future climate (Binkley, 1987; Pittock, 1987).

Irish forestry has changed dramatically in the recent past and will continue to change into the future. The changes brought about to our forests by our future climate will be superimposed on these factors and, over time, may become inseparable from them.

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CLIMATE AND WEATHER, THEIR EFFECTS ON ANIMAL HEALTH

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Weather plays a vital role in the spread of many infectious diseases and also influences metabolic ones. The pathogens which need to survive for any length of time off or outside the host are critically affected by ambient conditions. These pathogens differ in different geographical locations depending upon the climatic conditions. These conditions also affect the host animals and, when involved, the intermediate or vector hosts.

It is frequently found that in the warmer climatic regions a greater array and number of pathogens and/or their vectors thrive. It may only require a very small increase in temperature to allow the survival of a particular organism or animal. With a slight upward change in overall temperature several tick species which carry many diseases and which now do not survive in these islands would so do. *Haemonchus contortus*, a nematode parasite of sheep and which up to recently was confined to southern Britain, now has spread northward and has recently been prevalent in the Cork, Waterford and Wexford region.

The ambient temperatures at which animals thrive, produce and ultimately resist pathogens is generally quite narrow (Smith 1989) and so any changes either way must be viewed with concern. Needless to say many factors come into play as do compensatory mechanisms within the animal itself. Wind chill, humidity, and sunshine may change greatly the survival time of pathogens or their ability to infect the host animals.

Before animals face the battle against myriads of viruses, fungi, bacteria and parasites, they must survive : Neonatal deaths can cause up to fifty percent of losses in animals. Dystocias, stillbirths, inhalation pneumonia *etc.* make up a great number, but also weather stress, especially cold stress. Lambs which are frequently born outdoors in early spring suffer great losses. They are brought from a constant environment in utero to one of wind, rain or snow and temperatures often approaching $0^{o}C$. In bad winters it was estimated that up to four million lambs were lost in Britain due to neonatal cold stress (Wiener *et al.*, 1973). In these cases weather forecasting can forewarn shepherds to erect wind breaks, and ensure sufficient intake of food energy to at least match output of metabolic energy and also to try to avoid mismothering. Cold conditions in causing a decrease in intake of colostrum decrease the concentration of material antibodies and so decrease the resistance to infection in the new-born animal. Hot conditions may also decrease the intake of colostrum (in the new born) and generally may decrease the synthesis of some antibodies (Kelly, Blecha and Regnier, 1982).

Although weather conditions affect the host's metabolism and resistance and so indirectly the transmission of all diseases, weather plays a very definite role in many specific diseases, and any overall change in weather conditions may tip the balance in favour of the pathogen.

Physical Effects of Weather

The physical effects of changes in weather patterns must be borne in mind ; if electrical storms increase, then death from lightening may become more common. Extremes of weather, such as storms, intense cold, or drought limit food supplies which keep animals in good condition and are stress factors in themselves. Sunburn which occurs commonly in fish farms in the southern states of the USA occurs occasionally in farmed fish in this country and may become more common. Sunburn also occurs in light-coloured pigs and with free range pig farming gaining in popularity this may become a problem.

Photosensitization occurs in cattle and is linked to the effects of sunlight on the animals when they have ingested a photosensitizing agent. These agents occur in some plants and drugs. It is seen in Friesian cattle quite common.

It is clear that the stress caused by any appreciable period of unusually cold or usually hot conditions will affect production levels as the animals metabolism adjusts to try to counteract the loss or build-up of heat. This will be shown in loss of weight-gain or milk production or other parameters.

Metabolic Effects

Specific metabolic effects are seen in animals under extremes and already in Ireland considerable losses are suffered in livestock due to metabolic diseases. Cows suffer from hypocalcaemia when stresses of high production coupled with cold stress cause a drain of available calcium, leading to a tetanic condition which, if untreated, is fatal. Cows also suffer from hypomagnesaemia under similar conditions. This disorder may also appear in late spring after a sudden very mild moist spell which leads to a flush of grass, low in dry matter and hence low in minerals, including vital magnesium. A condition called "cold cow syndrome" has been noted in recent years and is also thought to be related to low available metabolic magnesium.

Ewes bearing twins suffer twin lamb disease or pregnancy toxaemia, a metabolic disorder due to the stress of pregnancy and low food availability in cold winter conditions. The extreme needs of pregnancy and low food availability in cold winter conditions. The extreme needs for energy cause overloading and the metabolic pathways become disrupted. Smith (1970) reported this disease to occur after periods of snow when ewes were deprived of food for a period.

Snow can help prevent swayback in lanbs by promoting the feeding of concentrates to the pregnant ewes thus so ensuring adequate copper for myelinization of the nerves in the embryo lambs. After mild winters this condition is more common in the following season's lambs ; Smith and Ollerenshaw (1967) suggested that allowing access to soil helps prevent the condition.

Effects on Infectious Diseases

The stress of extremes of weather on animals lowers resistance and facilitates the entry of infectious agents. This is so in the case of bacterial infections. Otherwise weather has little direct influence on bacterial disease although sunlight and dessication help kill bacteria outside the body while on occasion floods can disseminate them. Clostridial spores can survive long periods in mud and when it is exposed in drought conditions animals can ingest the spores, such as those of *Bacillus anthracis* and suffer anthrax. *Clostridium botulinum* survives in such a manner and water fowl exploring exposed mud for food during warm summers come in contact with the toxin and organism and suffer botulism from the toxin. This is called limberneck, due to the paralysis of the neck muscles, and the ensuing appearance. This lowered resistance, leading to increased disease, in extreme conditions can be seen in increases in *Pasteurella* pneumonia and *Escherichia coli* scours in pigs during cold conditions (Armstrong and Cline 1977), and *Salmonella sp* infections in chicks (Soerjadi et al 1979). *Rhodococcus equi* is more common in hot conditions and is thought to be spreading northward.

In Northern Ireland significant correlation coefficients were found between the percentage condemnations due to pleurisy and pneumonia in sheep, and records of rainfall, windspeed, temperature and humidity (McIllroy *et al.*, 1989). Dennis (1986) has reviewed the effects of temperature and humidity on several diseases of animals and linked low temperatures and high humidity to increases in occurrence of many diseases.

Cold conditions also frequently exacerbate the effects of many viral infections, as in the case of transmissable gastroenteritis virus of pigs (Shimizu *et al.*, 1978). But weather especially wind and humidity also plays an important role in directly transmitting viruses.

Airbourne transmission of viral diseases has long been documented (Smith 1971, Donaldson 1976, Hyslop and Hugh-Jones 1985 and 1989). Recently Power *et al.*, (1990) found a case of Aujeszky's disease in a cow which was linked to wind spread from a piggery. Christensen *et al.*, (1990) did likewise in Aujeszky's disease outbreaks in pigs, and demonstrated infection spread up to 80 kilometres.

Spread of Foot and Mouth disease, Newcastle disease, Avian infectious bronchitis, infectious bovine rhinotracheitis, swine fever and other diseases has important implications especially when eradication schemes or clear areas are in operation and borders are involved. With stable air and suitable humidity viruses can travel many kilometres on the wind. The exact distance depends on other factors also, such as topography, UV light, precipitation from clouds, the size of the aerosol particles, electrical effects, and temperature changes. This whole subject area is well reviewed by Hyslop and Hugh-Jones (1989).

The mathematical model predicting the spread of Foot and Mouth disease is on a computer programme available from the Irish Meterological Service.

Besides direct transmission of viruses by wind, insects are major carriers of infection. These too can be transmitted by wind and were suspected of transmitting viruses great distances during storms (Sellers *et al.*, 1977).

Many species of ticks abound in tropical climates and several carry pathogens which they transmit to mammals when they feed on them ; flies such as *Glossina sp.* (Tse tse) transmit serious disease as do *Culicoides sp.* (midges). Standfast and Muller (1989) linked the spread of Bluetongue virus in Australia with the spread of *C.wadai* and they estimate that, with predicted "Greenhouse effect" changes, it will spread widely in Australia.

African horse sickness has spread northward into Spain and Portugal; it has been maintained in the local *Culicoides sp* and has been found in species common in France and Britain. The introduced virus could become established in these countries. If a climate change brings a temperature rise this disease may spread northward as the vector extends its range.

Temperatures also affect the expression of virus diseases in animals. O'Connor,(1992) has linked the incidence of bovine herpes mammilitis with weather patterns and Gunn *et al.*, (1991) have found that Infectious Bovine Rhinotracheitis, Parainfluenza-3 and Respiratory syncytial virus outbreaks in feedlots are more serious when low wind speeds prevail.

Any change in climate may affect bird migration patterns and so affect the spread of viruses. Ducks and starlings have been shown to carry Newcastle disease and avian influenza viruses.

The area of animal disease most affected by climate and thence weather is that of parasitism - either through the effects on their vectors or on themselves when they spend time off the host developing or organising to the infective stage. The effects of weather in slowing down, suspending or increasing infection rates are well known and veterinarians and others make use of this knowledge to issue forecasts, warnings and advice.

Those nematode parasites which have a direct cycle frequently prosper off the host in moist warm conditions when they metabolize faster and are protected from dessication. Warm dry or cold dry conditions are deleterious to the free living stages of parasites. Climate change may cause a major problem with nematode infections in Europe. Already we have the spread northward of *Haemonchus sp.* and there is an increasing problem of anthelmintic resistance making the control of parasitic gastroenteritis more difficult. This disease has been found in Ireland in horses (O'Brien *et al.* 1990) also in sheep (O'Brien 1991), and is widespread in Europe. If requiring greater emphasis on husbandry host resistance breeding, vaccines, etc.

The spread of Coccidia and lungworms of all species is enhanced in moist mild conditions. The snail *Lymnea truncatula* which acts as an intermediate host to *Fasciola hepatica* (liver fluke)thrives in wet mild conditions and could be a possible loser in any increase in temperature if linked to drier climate. An overall temperature increase alone would just increase the occurrence of liver fluke disease. This disease is the subject of a well established forecasting system (Ollerenshaw *et al.*, 1966, 1969) which is accurate and helpful. It is issued each year by the Veterinary and Meteorological Services. Weather conditions are also taken into account in forecasting nematodiriasis and coccidiosis. Hyobiosis in *Ostertagia sp* infection is influenced by temperature ; and an increase in late summer and autumn temperatures may eliminate what is a serious and unpredictable disease situation, i.e. ostertagiasis type II. The local tick *Ixodes ricinus* carries several pathogens including *Borrelia burgdorferi*, louping ill virus, *Cytoecetes phagocytophila* and *Babesia divergens*, the cause of redwater disease. Ticks have annual biphasic activity which is predictable. With changes of climate there may be more intense periods of activity and hence a greater propensity for disease spread.

Most other ectoparasites such as flies, causing myiasis in sheep, lice on livestock and mites, are all affected by weather conditions and corresponding husbandry ; Moist mild weather favours the multiplication of flies but *Hypoderma sp.* fly stronger and spread further in warm dry conditions. Lice affect livestock worst in winter when the animals' resistance is lower and wherecloser proximity facilitates contact spread.

Likewise weather, including temperature, humidity, wind and sunlight have effects on fungal diseases such as ringworm and rainrot.

Summary it can be seen that not only are diseases of animals intimately linked to weather conditions but that changes in these conditions in the longer term can increase or decrease dramatically the incidence of these diseases and sometimes allow to flourish others which are at present exotic. It is vital that all those with an input into these areas of correlation monitor closely changes and movements and advise timely defensive measures when possible.

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METEOROLOGICAL SERVICE FOR DUTCH FARMERS IN THE PAST, PRESENT AND FUTURE

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The Early Years

The Dutch Meteorological Office (KNMI) which was founded in 1854 was charged with the task of providing weather forecasting for fishing, the navy, shipping and agriculture. In an era without radio, telephone, television and in the countryside without regularly available newspapers this task must have sounded futuristic to the meteorologists and potential users.

By the end of the 19th century farmers' schools had started, meteorology was one of the subjects, and, in the agricultural university fonded in 1918, at Wageningen the department of physics and meteorology existed from the outset. One of the first research subjects concerned solar radiation, and the widely known Kipp solarimeter was one of its first accomplishments.

Attention was also focussed in water stresses in tillage crops and on drainage. Meteorological research thus developed more and more in the direction of micrometeorology which culminated in the publication of the textbook "Physics of Plant Environment" (edited by van Wijk).

Statistics of rainfall, soil temperature, freezing of soils, windbreaks were compiled and many theses were written on hydro-meteorological subjects such as relations between rainfall distribution with time as well as in space, river discharges, snowmelt and evapotranspiration.

One of the first special activities was started by the manager of the butter mill at Gendringen, a small village near the German border in the vicinity of Emmerich. The Met. Office sent a telegram with the weather forecast twice a day to the postoffice in the village. The manager of the mill had developed a sound morse-code which was distributed among the farmers. After coding the weather forecast, it was broadcast by the steam whistle of the mill at noon and at 18.00 hours until it terminated in 1935.

Immediately after World War II the Met Office started a special weather forecast for farmers at 5.45 and 6.45 a.m. and at approx. 12.30 p.m.. These transmissions were mainly characterized by an extensive discussion of the weather situation. Some special information was added, for example, ground frost, timing of beginning and ending of precipitation, and sunshine duration in the next 24 hours. Also warnings about potato blight and apple scab based on past weather was inserted. These messages were warnings about possible infections and diseases of plants made in hindsight - they were not forecasts ! This situation lasted until 1985 with only some minor changes.

During the 1970's it became aware that it must be possible to provide the farmers with better information about weather. Farmers and officers of the advisory service in general had an insufficient knowledge of meteorological processes in order to translate the weather forecast into activities or advice on farms. In addition most meteorologists did not have enough knowledge either of agriculture or of micrometeorological processes to make scientifically based forecasts. The Dutch Met Office meanwhile was in the position to provide meteorological information by radio while the Dutch broadcasting companies started a policy of transmitting messages for a broad audience only. This resulted in the disappearance of specialized weather forecasting for farmers. In the middle of the 1980's information systems for agriculture started and included weather information. It developed into weather forecasts of a specialized character on teletext on a region-by-region basis.

The Present Services

Meteorological information is currently supplied according to geographic location or physiographic region. (Fig.1)

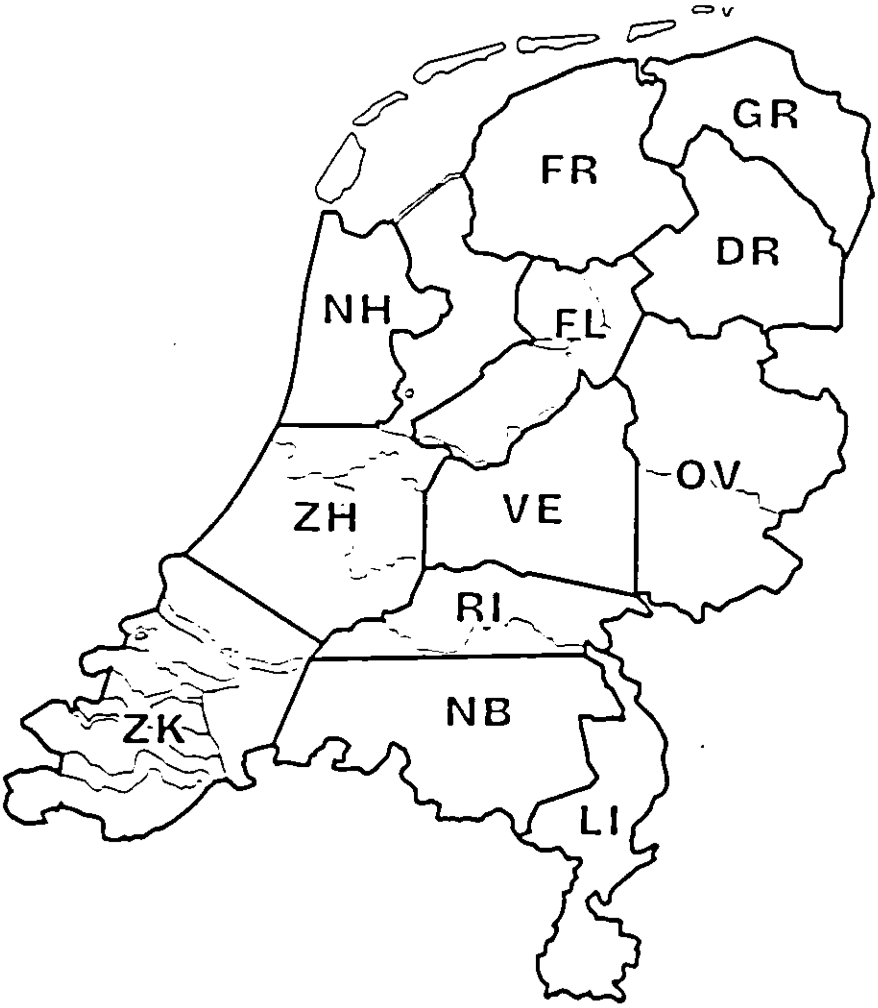

Figure 1 Agroclimatological zones

Although the distances are small, the difference in the weather between the coastal region, say less than 50 km from the coast and the central and eastern part of the country is quite large. Differences in flowering, and time differences in bud-burst of 4 weeks is not exceptional. Similarly, differences in soil behaviour have a considerable influence, especially on night temperatures, dew amounts, leaf wetness periods, *etc.* Tables 1-5 record long and short term present data (various parameters) for the Rhine/Maas region with predictions for spraying opportunities outlined in Table 6.

Table 1 : Short range forecast of temperature and wind for the Rhine/Maas region issued 0.600 Monday October 14 (next forecast 09.00).

	hour				
	09.00	12.00	15.00	18.00	21.00
Temperature at 1.5m (°C)	12	16	17	15	14
Temperature at 0.1m (°C)	12	19	17	15	13
Dewpoint at 1.5m (°C)	9	10	10	10	10
Windspeed (ms^{-1})	2	2	2	2	2
Windforce (Beaufort)	1-2	2-3	2-3	2-3	1-3
Wind direction	S	S	S	S	S
Max. windgust at 2m(ms^{-1})	4	4	4.5	4.5	3.5
Thermals	M (moderate)	M	M	L (light)	L

Table 2 : Short range forecast of humidity and precipitation for the Rhine/Maas region issued 06.00 Monday October 14. (next forecast 09.00)

	hour				
	09.00	12.00	15.00	18.00	21.00
Rel. humidity (%)	85	65	65	75	80
Cloudiness	4/8	4/8	4/8	5/8	5/8
Prob. of precipitation %	20	25	30	30	30
Precipitation, mm			< 0.5		
Pot. evapotranspiration, mm			1.7		

Table 3 : **Long range forecast of precipitation and evaporation for the Rhine/Maas region for Monday 14 October, together with previous week's evapotranspiration data.**

	Tues	Wed	Thurs	Fri
Probability of Precipitation, %	45	80	75	75
Precipitation amount, mm	1-3	15-21	8-14	4-8
Pot. evapotranspiration, mm	1.1	0.7	1.1	0.9

	Sun	Sat	Fri	Thurs	Wed	Tues	Mon	Total
Last Week's ETp, mm	0.7	0.7	1.6	1.7	1.3	1.4	0.9	8.3

Table 4 : **Long range forecast for temperature and wind for the Rhine/Maas region issued Monday 14 October.**

	Tues	Wed	Thurs	Fri
Minimum temp. ^{o}C	9	12	10	7
Maximum temp. ^{o}C	15	13	11	11
Dew point ^{o}C	9	12	7	3
Frost duration,h	0	0	0	0
Wind speed, ms^{-1}	2	5	6	7
Wind force (Beaufort)	2-3	4-5	4-6	5-6
Wind direction	S	SSW	W	W
Thermals	-	-	-	-

Table 5: **Long range forecast for sunshine and humidity for the Rhine/Maas region, issued Monday October 14.**

Dry	Tues	Wed	Thurs	Fri
Sunshine, hr	2	0	3	2
Global radiation ly cm^{-2}	0.7	0.4	0.8	0.6
Minimum rel. humidity (%)	70	90	75	60
Minimum Vapour deficit, mb.	5	2	3	5
Dew intensity	0	0	-	-

Table 6 : **Forecast of weather conditions for spraying, Rhine and Maas region, issued Monday 14 October.**

	Mon	Tues	Wed	Thurs	Fri
Suitability for spraying	+	++	- -	- - - -	
Windspeed at 2m (ms^{-1})	2	2	5	6	7
Max. gust, (ms^{-1})	4	5	11	12	13
Thermals	0	-	-	-	-
Max. temp. (^{o}C)	17	15	13	11	11
Sunshine, hr	5	2	0	3	2
Rel. humidity (%)	65	70	90	75	60

Drying of the cut grass is one of extreme importance to many farmers. Several diagnostic models which describe the drying of grass are available. Generally speaking the models with the best physical basis are diagnostic. The models show that the swath temperature is very important for the drying process.

If fresh grass lies on top of a cut swath its temperature is low and it takes time to increase. In practice, most farmers are anxious to ted two or three times a day. However, tedding means mixing and a decrease of temperature results. Advanced physical models of grass drying suitable for prognostic purposes have been developed and one has been published (Atzema 1991). This model is used in combination with the so-called "WITAK" forecast system. A second and more advanced model is currently being tested at the Dept of Meteorology, Wageningen University. This model has already been used in practice for one year (Tables 7a and 7b).

Table 7a : Predicted dry matter content of cut grass :
(a) Rhine/Maas region, 14 October 1991,

	Mon		Tues		Wed		Thurs		Fri	
Day of mowing	1400	1000	1400	1000	1400	1000	1400	1000	1400	1000
Mon	20	25	30	35	15	15	15	20	15	20
Tues			20	25	15	15	15	20	15	20
Wed					15	15	15	20	15	20
Thurs							15	20	15	20
Fri									15	20

Table 7b (b) Overijssel/East Gelderland region, 1 July 1991.

	Mon		Tues		Wed		Thurs		Fri	
Day of mowing	1400	1800	1400	1800	1400	1800	1400	1800	1400	1800
Mon	22	28	36	42	49	55	59	62	65	62
Tues			23	30	38	46	51	55	60	63
Wed					24	33	40	45	51	56
Thurs							22	29	37	43
Fri									24	31

A farmer who wishes to use this model provides data of the time planning of grass cut and the estimated yield by telephone. In addition he provides his planned scheme for tedding with one or more alternatives. After giving his ZIP-code he will receive the model results. A typical printout is given in Figure 2.

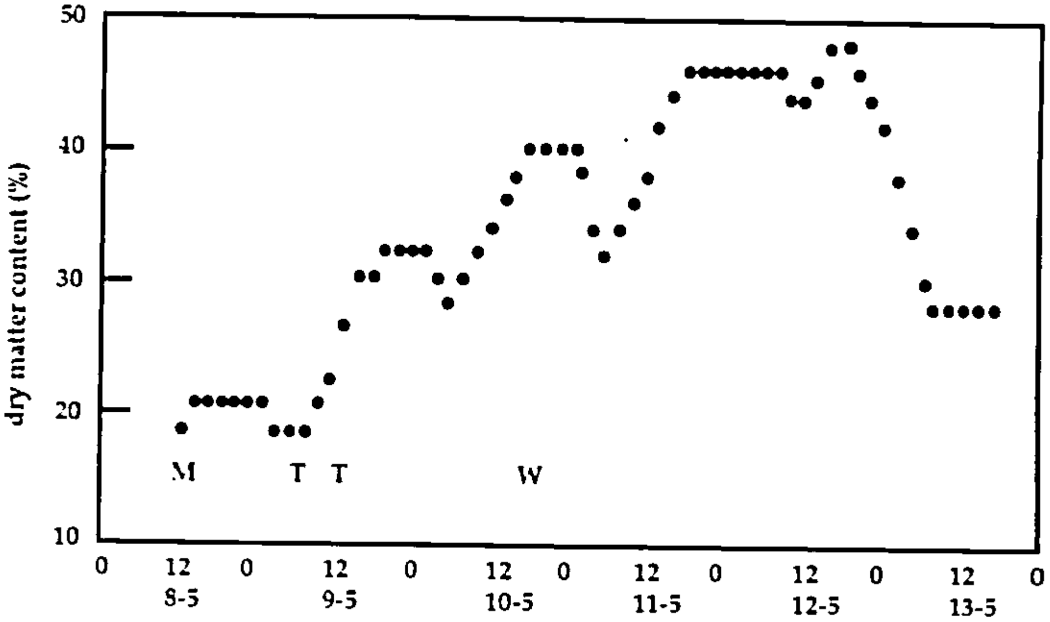

Figure 2 Course of the dry matter content of cut grass based on the weather prognosis at 8th May. (M = Mowing, T = Tedding, W = Windrowing) The quantity of dry matter was estimated at 1200 Kg/ha. The desired dry matter content of 40% will be reached on 11/5/91 at 14.00h.

Other forecasted items include the content of moisture of cereals in order to make decisions about the harvesting date, and conditions suitable for storage of potatoes and onions (Table 8).

Table 8 : **Forecast of conditions suitable for storage of potatoes and onions, Rhine/Mass region.**

	Mon		Tues	Wed	Thurs	Fri
	day	night				
Max. temp (^{o}C)	17					
Min. temp (^{o}C)		9	9	12	10	7
Dewpoint (^{o}C)	10	8	9	12	7	3
Safe storage temp. for ventilation (^{o}C)	12	12	11	14	9	5

In 1982 separate weekly information package on forthcoming weather was made available to Agricultural advisers in Regions R1, Ve and Ov (Fig.1). Region Fl was included in 1985. The following is an example for May , 1990.

> "The weather conditions are expected to be : dry, sunny, a moderate NE wind. Afternoon air temperatures between 20 to 23°C. Minimum air temperatures between 0 and 5°C. Much dew formation, and probably fog.
> In contrast to the past nights, the chance of ground frost is negligible. Soil temperature in the upper 5cm of the soil is around 25°C in the afternoon and 6-10°C at night. The crop transpiration is about 4 mm a day.
>
> Grass: All days are suitable to ensile grass. Stop in time since early dew-fall is expected.
>
> Strawberries : Crops under plastic tunnels and greenhouses are near ripening. Occasionally, wilting occurs which can have various causes. Help plants by providing them with small amounts of water, and in addition, chalk the glass slightly. Gardeners who grow their plants in baskets or peat bales should not underestimate water consumption. In some cases the watering has to be done hourly. Plants can also be helped to withstand the sudden shock in weather change by lowering the fertiliser concentration of the irrigation water.
>
> Strawberries in the field : Aphids are very plentiful and they will be very active this week ; hence it is urgent to undertake control measures.
>
> Horticulture : The blight caused by the fly *Delia brassicae* has started and will spread this week. In carrots the *Psila rosae* will become active and a soil treatment is urgent now.
>
> Lettuces under plastic sheet become too hot this week. A sudden removal of the sheet causes a too great a shock. This can be prevented in two ways :
>
> 1. Sprinkle irrigation over the sheet.
> 2. Remove the sheet in the late afternoon at once followed by a mild sprinkle irrigation, and a repeated sprinkling in the early morning next day. However do not sprinkle in bright sunshine.
>
> Orchards : The weather is favourable for the second fructification of apple. For orchards where the first fructification is damaged by groundfrost, the tree can be helped by bending down upward operating sprays and eventually spraying of a fructification-promoting medium.
>
> Fungi: The weather will be favourable for mildew. If there are still visibly affected parts from the past year, prune these parts immediately.
>
> Control measures against the gloeosporium disease in apple with captan can be omitted if the weather behaves as predicted. The same can be said about apple-scab (*Venturia inaequalis).*

Watch for Lygus species in pears. By the end of the week swarming of the plant louse *Lepidosaphes ulmi*; and of the gall midge *Dasineura mali* is to be expected.

Arable farmers :Potatoes come up very rapidly now and hence weather control is urgent. Watch the occurrence of aphids and mildew in wheat and winter-barley.

Winter-wheat :*Pucinia reconditor* is observed in winter-wheat in the province of Gelderland. Although it is very early in the year, control is necessary to prevent an outbreak.

Sugar-beet:

1. The plant population limit which must be drilled has been decreased to 35,000 to 40,000 plants per hectare.
2. For low-doses weed control system the weather seems to be excellent. However, because the weeds are hardened off, increase the oil.
3. Flights of the sugar-beet beetle (*Atomaria linearis*) can occur. Thus, be watchful of seedlings.
4. Louse/aphid control is necessary if more than 2 green lice/aphids are observed per 10 plants".

It is very unlikely that this kind of forecasting will be developed further. The broadcasting companies try to reach as broad an audience as possible while only a small number of people is interested in farming. In the long run, the tendency is that this type of forecast will be continued by the on-line information systems. It can then be updated twice a week, or more if necessary. In central Europe, information systems are not yet available and this will not change in the course of years ahead. We receive requests from Poland to support them in order to develop the organisation for this kind of help for the farmer.

The Future

What about help for farmers if a climate change occurs ? But, will there be a climatic change, and, if so, how do we become aware of it ?
In fact none of the available climate models are capable of calculating weather phenomena. If we look backward, we observe years with very little warm summer weather, mild years without severe frost, warm springs with severe groundfrosts and cold wet summers with normal duration of sunshine and high yields. There are summers with high yields but with bad harvesting conditions, resulting in high costs and losses. Besides that, it is illogical to expect that if a global warning will come, all other weather phenomena are unchanged and only a higher temperature level experienced.

It is worthwhile to study what actually happened during minor climatic deviations in historical time. Lamb (1981) give us a lot of information on this item. The following is a brief summary:

Climatic changes are manifest in changes of the frequencies of rare events. That can be a higher frequency of extreme wet summers, or a lack of extreme cold winters and so on. Until now, our farmers also never knew how the weather will be in the next season. For a couple of days ahead, we can advise them. The more a farmer learns from bad weather conditions, the better he will be able to adapt to a climatic change, which we surely can state only in hindsight. I will conclude by mentioning results of studies about crop yields into cold, normal and to warm seasons. In temperate zones, the highest yields were in the warm season. But if other variables *e.g.* precipitation or sunshine duration were included, then combinations of normal weather situations always have given the best results for farmers. The conclusion can be that farmers all over the world know how to do their jobs properly. Even in this area with fast changing methods and techniques this is still the case.

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INTERACTION OF GASEOUS EMISSIONS FROM AGRICULTURAL ACTIVITIES WITH FOREST ECOSYSTEMS.

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ABSTRACT

The principal gases emitted to the atmosphere as a result of the utilization of land for agriculture are those of carbon, sulphur and nitrogen. The most immediate effect of gaseous emissions from agriculture may be attributed to the nitrogen gases and in particular, ammonia. About 90% of NH_3 emissions to the atmosphere are attributable to livestock production. Ammonia is the most abundant alkaline component of the atmosphere. Its residence time in the atmosphere is only a few days. Ammonium by contrast, is transported considerable distances. High nitrogen inputs can influence forest ecosystems both through direct damage to the foliage and within the plant and the soil. Increased acidification occurs whether nitrogen reaches the system as NH_4^+ or as NO_3^-. The potential hazards of pollutant deposition are embraced in the critical load concept. Critical loads for coniferous forest are of the order of 5-20 kg N ha^{-1} $year^{-1}$. In Ireland, nitrogen deposition in precipitation and throughfall in forests is measured in a series of four forest ecosystem monitoring plots operated by the Forest Ecosystem Research Group in UCD. The plots are located in Wicklow (Roundwood), Cork (Ballyhooly), Galway (Cloosh) and Mayo (Brackloon). Each site has an open, non-forested counterpart. Deposition of NH_4^+-N and NO_3—N at the two western sites is very low. The values at Roundwood are quite high, in excess of general estimates of critical load for N. A study is presently underway at Ballyhooly to examine the relationship between slurry and fertilizer spreading and NH_4^+-N deposition in throughfall. The moderate intensity of animal production at Ballyhooly, coupled with low ambient atmospheric NH_3 concentrations, provide an opportunity to record the effect of individual spreading operations on atmospheric and rainfall chemistry within the boundaries of the forest. The data show clear evidence of locally produced NH_3. It is intended to conduct a similar survey with more intensive monitoring of rainfall, throughfall, gas concentrations and weather conditions in 1992.

INTRODUCTION

The principal gases emitted to the atmosphere as a result of the utilization of land for agriculture are those of carbon, sulphur and nitrogen. The major gases and the contribution of agriculture to total emissions of each are shown in Table 1. The carbon gases are the most abundant. Agriculture is a major contributor to total emissions of two of them, carbon monoxide (CO) and methane (CH_4). With carbon dioxide (CO_2), these are the most important gases which may be contributing to climatic change. Fires in tropical regions are the most important source of CO. Much of the methane of agricultural origin emitted to the atmosphere also results from the burning of biomass for land clearance. Paddy rice growing is also an important source of this gas, but fermentation by ruminant animals is estimated to contribute 25 to 35% of total emissions of methane to the atmosphere (Isermann 1991). Whatever the long-term effects of greenhouse gas emissions on global warming, the most immediate effect of gaseous emissions from agriculture may be attributed to the nitrogen gases and in particular, ammonia.

Table 1. Contribution of agriculture to gaseous emissions to the atmosphere.

Gas	Symbol	Agricultural Contribution %
Carbon monoxide	CO	38
Carbon dioxide	CO_2	15*
Methane	CH_4	45-52
Hydrogen sulphide	H_2S	neg.
Dimethyl sulphide	CH_3SCH_3	neg.
Sulphur dioxide	SO_2	neg.
Ammonia	NH_3	90
Nitrous oxide	N_2O	30-40
Nitrogen oxides	NO_x	<20

* % anthropogenic emissions
neg. = neglible
Sources cited by Isermann (1991)

Nitrogen is the most abundant component of the earth's atmosphere. Dry air, at sea-level, contains, on average, 78.08% elemental nitrogen (N_2) by volume. Nitrogen from the atmosphere is converted, principally by biological processes, to forms which can be utilized by higher plants and which are incorporated ultimately into proteins. Not only is nitrogen an essential element for plants and animals, it plays a peculiarly complicated role in life processes. Much of the nitrogen that is used in biological processes is involved in the so-called nitrogen cycle, in fact a series of intermeshing cycles within the soil, between the soil and higher plants and animals and between the soil and the atmosphere. Nitrogen is able to play this complex role in life processes because it has an unusually large number of oxidation levels which enable it to combine with hydrogen, oxygen and other atoms to form a great variety of compounds. Nitrogen emissions to the atmosphere occur principally as five gases, ammonia (NH_3), nitrous oxide (N_2O) nitric oxide (NO), nitrogen dioxide (NO_2) and dinitrogen (N_2). Because of the major human influence on the quantity of gaseous emissions of nitrogen, both total emissions and the relative contribution of different gases show marked variation, at continental, regional and local levels.

About 95% of NH_3 emissions to the atmosphere are attributable to human activity, 90% directly or indirectly to livestock production (Isermann 1991). The principal source of NH_3 arising from livestock production is urea in urine. Losses arise primarily from the collection, storage and distribution of liquid and solid manures. Smaller, but locally significant losses of NH_3 occur as a result of the manufacture and the use of nitrogenous fertilizers.

Because of the high temporal and spatial variation in NH_3 concentrations, few reliable annual mean values are available. Asman and Janssen (1987) used a long-range transport model to compute atmospheric concentrations of NH_3 and NH_4^+ for each country in Europe. The computed NH_3 concentration for Ireland was 2.1 ug m^{-3}. This can be compared with the extremes of 0.1 ug m^{-3} for remote maritime regions (Gravenhorst et al. 1983) and an annual average of 5.5 ug m^{-3} in the Netherlands (Erisman and Heij 1991).

NH_3 is the most abundant alkaline component of the atmosphere. It is quickly converted to NH_4^+. Typically, its residence time in the atmosphere is only a few days and it is rarely transported more than 250 km (Erisman and Heij 1991). In Europe, it is estimated that 90% of dry deposition occurs in the country of origin (Asman and Janssen 1987). Ammonium by contrast, may be transported more than 1000 km (Erisman and Heij 1991). Nevertheless, it has been estimated (Asman and Janssen 1987) that 88% of the total deposition of ammonia and ammonium in Ireland is home-produced.

Compared to ammonia, the other nitrogen gases of agricultural origin are less significant. The contribution of agriculture to emissions of nitric oxide (NO) and nitrogen dioxide (NO_2), collectively known as NO_x, is relatively small. The main source of NO_x is combustion, especially high-temperature combustion associated with the internal combustion engine. NO_x is chemically active in the troposphere. It returns to earth principally as nitrate or nitric acid (HNO_3).

Soils are the major source of N_2 through the denitrification and nitrification processes (Jenkinson 1990). Denitrification results in the loss to the atmosphere of nitrogen as nitrous oxide (N_2O) or dinitrogen (N_2). Of the N_2O emitted to the atmosphere, very little returns to earth. Denitrification also occurs in sediments of both fresh- and sea-water bodies. The quantity of N_2 lost to the atmosphere is unknown, but it may be by far the largest of any of the nitrogen gases (Jenkins 1990).

Pollutant Deposition

Pollutant deposition occurs not only in precipitation (wet deposition), but also as aerosol and dust particles (dry deposition) and associated with fog and mist (occult deposition). Fog is particularly important in forest ecosystems because of its prevalence in mountain regions. Contact time with foliage is longer than with rain and pH values are sometimes one unit lower than the typical minimum value (pH 4.2) of acid rain.

Coniferous forest is particularly susceptible to the effects of air-borne pollutants because its foliage intercepts dust and aerosol particles and because it is often associated with thin, acid soils of relatively low buffering capacity. Broadleaved forests also intercept pollutants, but deciduous trees, not surprisingly, intercept less, on an annual basis. In addition, broadleaved forests usually grow on more fertile soils.

Due principally to interception by forest canopies, the so-called "scavenging effect", throughfall in forest ecosystems typically has both higher concentrations and higher deposition levels of most ions, than bulk precipitation. This is illustrated for ammonium in three coniferous forest ecosystems in Figure 1. Under the high levels of intensive animal production prevailing in the Netherlands, the interception of dry-deposited NH_3 and NH_4^+ is much greater at Kootwijk than at the Solling, an industrially polluted region of Germany or at Ballyhooly near Fermoy, Co Cork.

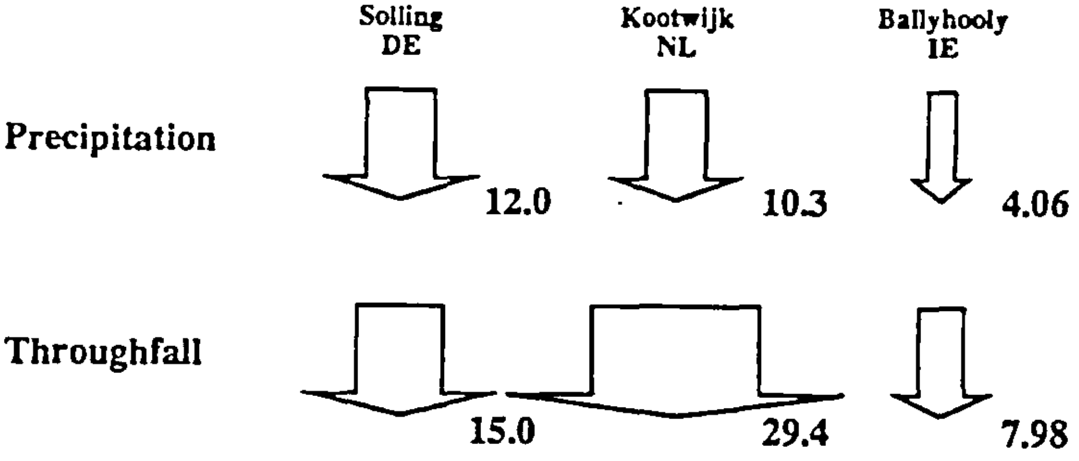

Figure 1. Ammonium deposition (kg N ha^{-1}) at selected EXMAN sites in Europe.

High nitrogen inputs can influence the forest ecosystem both through direct damage to the foliage and indirectly within the plant and the soil. Polluted air is usually a cocktail of phytotoxic chemicals making it difficult to attribute damage in the field to a single constituent of the atmosphere. Although ammonia is the principal phytotoxic component of the gases associated with livestock production, amines, hydrogen sulphide and organic acids, all of which are potentially toxic, are also emitted (van der Eerden 1982).

It is possible, in controlled, growth-chamber studies, to examine the effects of a single component or a regulated mixture of gases, but with forest species, work must be confined to small plants, except in a few very large open-top chamber units.

Direct toxic effects of NH_3 are not very common under field conditions (Heij *et al.* 1991). However, browning of conifer needles in dry summers and increased susceptibility to winter frost are commonly associated with damage to forest stands close to livestock production units. Sensitivity to cold has been observed in controlled experiments with a range of species including common conifers (van der Eerden 1982), although most of the symptoms observed in this study were similar to those caused by other stress factors such as drought, some plant diseases, salt and other pollutants.

Both NH_3 and NH_4^+ can be absorbed through leaves, but their effect is potentially toxic. Plants are most susceptible to this interference when carbohydrate supply is low. This mechanism could explain the observed high sensitivity of conifers to NH_4^+ in winter. Foliar absorption of NH_4^+ results in the leaching of other nutrients, notably potassium and magnesium (Roelofs *et al.* 1985).

Nitrogen Saturation

Widespread fertilizer use became popular in forestry in the 1960s. In most cases, nitrogen was the element which gave the greatest growth responses. Poor management practices and in particular, the removal of tree foliage and plant litter from the forest for use as fodder and bedding for animals respectively, resulted in the development of serious nutrient deficiencies over considerable areas in former times (Tamm 1968).

It was only in the 1980s that scientists and forest managers became fully aware that not only had the nitrogen deficiency problem largely disappeared, but that forest ecosystems were becoming subjected to excessive inputs of nitrogen from the atmosphere. The possibility of nitrogen saturation of ecosystems was raised by NihlgÜrd (1985) and although not universally accepted, it is acknowledged that excessive nitrogen inputs can lead to the degradation of forest ecosystems.

Nitrogen deposition can and does promote growth in many forest ecosystems where supplies are inadequate for optimum growth. This fertilizing effect is common in the early stages of pollution or at relatively low levels of atmospheric deposition. However, excessive nitrogen deposition inhibits mycorrhizal activity in the soil, it leads to disturbances in nutrient balance and it results in increased rates of soil acidification. Increased acidification occurs whether nitrogen reaches the system as NH_4^+ or as NO_3^-. NH_3 is the principle alkaline gas in the atmosphere. As such, it reduces the acidity of precipitation by absorbing protons, but only if it is present as NH_3, in other words, only if it is generated locally. If it is transported into a region as NH_4^+, it has already taken up protons and will not influence rainfall pH at the point of deposition. In any event, the neutralising effect of NH_3 is illusory as it results in an increase in proton generation in the soil. The protons absorbed by NH_3 in the atmosphere, or on the forest canopy are released either on the uptake of the NH_4^+ by plants, or during its transformation to NO_3^-. NH_3 influences the uptake of sulphur dioxide (SO_2) in the atmosphere by causing a rise in pH which enhances the rate of oxidation of dissolved SO_2 by ozone (O_3). More SO_2 will be taken up by cloud droplets and oxidized to SO_4^{--}(Asman and Janssen 1987).

NO_3^- may enter the forest ecosystem as nitric acid. However, plant uptake of deposited nitrate will generate one mole of bicarbonate (HCO_3^-). NO_3^- deposited in the ecosystem, or generated as a result of nitrification, if not quickly taken up by the vegetation or soil microflora, will be leached from the ecosystem. Hydrogen is often the cation accompanying the NO_3^- when it is exported from the ecosystem. NO_3^- leaching may thus lead either to the eutrophication, or to the acidification of adjacent aquatic ecosystems.

While there is disagreement in the literature on the precise definition, an ecosystem may be considered to be N saturated when the output of N or exceeds the input (Ågren and Bosatto 1988). In practice, high NO_3^- leaching (more than 10 kg N ha^{-1} $year^{-1}$) from an actively growing forest stand can be taken as an indication of N saturation. Denitrification may, by increasing under conditions of nitrogen saturation, to some extent, counteract the effects of high N input (Gundersen 1991). While denitrification fluxes in forest soils are generally considered to be very low (less than 1 kg N ha^{-1} $year^{-1}$), a figure for total N loss through denitrification, of 3.2 kg N ha^{-1} $year^{-1}$ (80% as N_2O) has recently been reported from a Sitka spruce *(Picea sitchensis)* plantation on a peaty-gley soil in the United Kingdom (Ineson *et al.* 1991).

Critical load Concept

The potential hazards of pollutant deposition are embraced in the critical load concept. Critical load is defined as a

> "quantitative estimate of an exposure to one or more pollutants below
> which significant harmful effects to specified sensitive elements
> of the environment do not occur, according to present knowledge."

Critical load maps of acidity, sulphur and nitrogen have recently been produced for Europe (Hettelingh *et al.* 1991). The critical load of nutrient nitrogen has been further defined as

> "the maximum deposition of nitrogen compounds that will not
> cause eutrophication nor induce any type of nutrient imbalance
> in any part of the ecosystem or recipients to the ecosystem"
> (Sverdrup *et al.* 1990.).

Whereas for sulphur, the rate of chemical weathering in the soil controls the critical load, for nitrogen, organic matter transformations are of critical importance, in particular the fate of mineralized nitrogen in the ecosystem.

The maximum nutrient nitrogen input to an ecosystem can be described by the following equation:

$$\text{N load}_c = \text{N total}_u + \text{N total}_{acc} + \text{N total}_l$$

where

N load_c = Critical N load
N total_u = Permanent plant uptake of total N
N total_{acc} = Acceptable long-term accumulation of total N
N total_l = Acceptable N leaching.

In terms of eutrophication, acceptable leaching of NO_3^- will be determined by the concentration of NO_3^- that will cause eutrophication of an aquatic ecosystem, or will exceed NO_3^-concentration limits for drinking water.

Critical load for N can also be viewed either from the stand-point of its contribution to total acidity or in terms of an acceptable accumulation of ammonium in the soil. Contribution to total acidity is determined by the critical load for total acidity less the contribution from sulphate acidity. The accumulation of NH_4^+ in the soil is measured against possible nutrient imbalance with base cations as indicated by NH_4^+:K and NH_4^+:Mg ratios.

Critical loads for coniferous forest are of the order of 5-15 kg N ha^{-1} year^{-1}. Under conditions of conventional stem-only harvesting, the figure may be as low as 4-10 kg N ha^{-1} year^{-1} (Gundersen 1991). Over most of Europe, deposition is considerably greater than critical load. Average total N deposition (wet and dry) for north-west Europe has been estimated at 10-20 kg N ha^{-1} year^{-1} (Goulding 1990). Average deposition for the

Netherlands has recently been estimated to be 47 kg N ha^{-1} $year^{-1}$ (Erisman and Heij 1991), 65% as NH_x (NH_3 plus NH_4^+). This is a significant increase on previous estimates, due to an upward revision of NH_x deposition by 54%. Maximum values of nitrogen deposition are about 100 kg ha^{-1} $year^{-1}$ (van Breemen and van Dijk 1988).

Monitoring of Forest Ecosystems in Ireland

Nitrogen deposition in precipitation and throughfall is measured in a series of four forest ecosystem monitoring plots operated by the Forest Ecosystem Research Group in UCD. The locations of these plots are shown in Figure 2 and site and stand details are contained in Table 2. Each site has an open, non-forested counterpart. The forest stands were selected subjectively as representative of forest ecosystems which are important in Ireland. The first plot, established at Ballyhooly in Co Cork in 1988 was selected in order to provide a clean air counterpart to forest stands in polluted regions in Europe in general and to the experimental site Hoglwald of the University of Munich, in particular. The tree crop is a mature stand of Norway spruce (*Picea abies*) and the soil is acid and free draining.

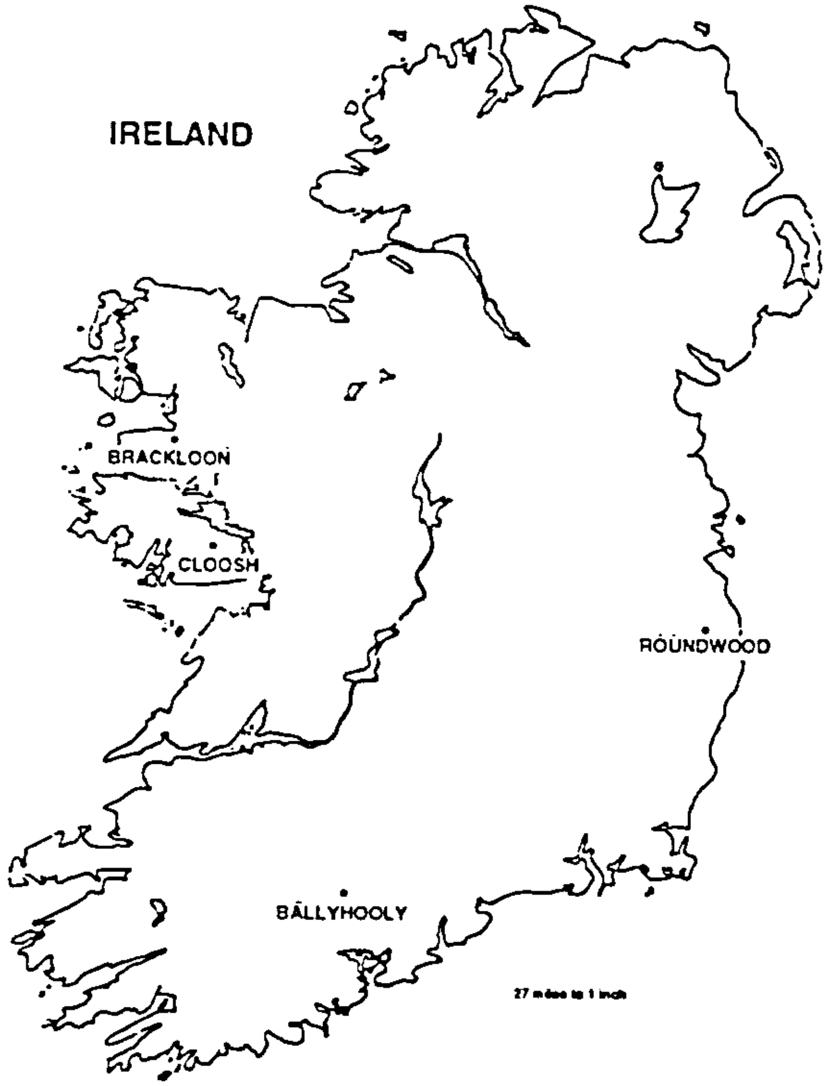

Figure 2 Location of Forest ecosystem monitoring sites

Table 2 Details of forest ecosystem motitoring sites in Ireland

Location :

Ballyhooly: Fermoy, Co. Cork (10km), slightly oceanic

Brackloon: Westport, Co. Mayo (6km), strongly oceanic

Cloosh: Oughterard, Co. Galway (10km), oceanic

Roundwood: Roundwood, Co. Wicklow (4km), slightly oceanic, sumbontane

Species and Age :

Ballyhooly: *Picea abies* L., planted 1939 :
Brackloon: *Quercus petrea*, Somewhat uneven, most oaks probably over 150 years
Cloosh: *Picea sitchensis* ; planted 1958 ;
Roundwood: *Picea sitchensis*, planted 1955

The other sites were established in 1991. Two are plantation forests, at Cloosh in Co Galway, on blanket peat and at Roundwood, Co Wicklow, on an acid mineral soil. The third (Brackloon) is a semi-natural oakwood (*Quercus petraea*). The soils at both Roundwood and Brackloon are podzolised. At each site, samples are collected, at regular intervals, of rainfall (bulk precipitation), throughfall (under the forest canopy), humus water (under the organic horizon of the forest floor) and soil water. In addition, stemflow collectors have recently been installed. Samples are collected in the forest stand and as appropriate, from a nearby open area. Atmospheric gases are collected from the open area with a High Efficiency Annular Denuder (HEAD). This instrument is installed periodically on a permanent platform to run for periods of about one week duration. Ambient air passes through the denuder under laminar flow conditions. Quantitative collection of gases is achieved by the use of appropriate sorbents as denuder coatings.

The Ballyhooly site is part of the EC-supported EXMAN (Experimental Manipulation of Forest Ecosystems in Europe) project. Ionic deposition in bulk precipitation for the EXMAN sites is shown in Table 3. Of the five sites, Ballyhooly (mean 1989, 1990) is clearly the least polluted. While SO_4^{--} in Kootwjik and Ballyhooly are equal, a much higher proportion of the deposition at Ballyhooly is of marine origin. Proton deposition is less than one fifth of that at any one of the other sites; NO_3- is about one third. Only NH_4^+ deposition at Ballyhooly approaches that at the other sites. Bulk precipitation and throughfall concentration data for three of these sites have already been presented in Figure 1.

Table 3 Deposition (kg ha^{-1} year^{-1}) in bulk precipitation at EXMAN sites in Europe

Element	Ballyhooly (Ireland)	Klosterhede (Denmark)	Kootwijk (Netherlands)	Höglwald (Germany)	Solling (Germany)
NH_4^+-N	4.0	6.2	11.8	5.9	12.0
NO_3—N	1.5	7.1	4.5	5.6	10.0
SO_4^{2}—S	6.9	15.3	12.8	10.4	23.0
H^+	0.03	0.41	0.19	0.16	0.9
Cl^-	85	95	28	7.3	17

Throughfall loads give a reasonable, although imperfect, measure of total (wet and dry) deposition of NH_4^+. In the Dutch Priority Programme on Acidification, deposition, as estimated by throughfall load was compared with estimates based on concentration measurements and estimates of dry deposition rate (Erisman and Heij 1991). While for some ions, there was a large discrepancy between the two estimates, for NH_4^+, throughfall measurements were only 13% higher on average. Differences are explained partially by deposition associated with fog and partially by exchange processes in the vegetation. Deposition of NH_4^+-N and NO_3^-N for the four monitoring sites operated by the Forest Ecosystem Research Group are given in Table 4. The two western sites have very low nitrogen inputs, as would be expected in relatively remote locations with low pollution levels. In fact, at both sites and for both NH_4^+-N and NO_3^-N, throughfall deposition is less than that in the bulk precipitation, suggesting that absorption by the vegetation represents a significant proportion of the input. A similar phenomenon was observed in throughfall NO_3^- in a lodgepole pine (*Pinus contorta*) stand at Glenturk in North Mayo (Farrell, 1990). The values for Roundwood are quite high, in excess of general estimates of critical load for N. The significant contribution of NO_3^- to the total N load and the absence of intensive agriculture in the vicinity of the Roundwood site, suggest a long-range pollution influence. At Ballyhooly, by contrast, NH_4^+ is more than twice that of NO_3^-, due probably to the fact that local (agricultural) pollution is more significant at this site.

Table 4 Throughfall deposition of nitrogen (kg N ha^{-1}) for 1991 at four forest ecosystem monitoring sites in Ireland

Site	NH_4-N	NO_3-N	Total inorganic N
Ballyhooly	8.25	3.62	11.87
Cloosh	0.91	1.38	2.29
Brackloon	1.26	1.17	2.43
Roundwood	10.53	13.14	23.67

There is, as yet, no indication of forest damage in Ireland, resulting from NH_3/NH_4^+ deposition. Widespread damage would certainly never be expected. Total NH_3 emissions in Ireland have been estimated by Sherwood and Tunney (1991) at about 130,000 tonnes per annum. This corresponds to 2.0 tonnes NH_3 km^{-2} which is low compared to other European countries. Of those listed by Sherwood and Tunney, the Netherlands is highest at 7.6 tonnes km^{-2}.

Behaviour of nitrogen species at Ballyhooly.

The data in Figure 3 give some measure of the variation in inorganic N concentrations between years. The concentration of NH_4^+ in precipitation was about 14% higher in 1990 than in 1989. Throughfall concentration however, was greater in 1989 over 1990, by more than 25%. This was due to greater dry deposition of NH_4^+ in 1989 and is probably related to weather conditions immediately following slurry and nitrogenous fertilizer spreading operations in the vicinity. No pH drop from bulk precipitation to throughfall was observed in 1989 suggesting that incoming protons were neutralised by NH_3 and collected in throughfall as NH_4^+, rather than as H^+.

One can only speculate as to why the humus water shows such variation between years. The more than two-fold increase in NH_4^+ concentration from the throughfall in 1989 indicates a high level of N mineralisation. This may be due to higher soil temperatures in that year. The increase in NO_3^- concentration is undoubtedly a reflection of increased nitrification, a consequence of both improved weather conditions and greater amounts of surplus NH_4^+ in the system. This NO_3^- is also apparently surplus to requirements as the concentration at 75cm, which is assumed to represent water leaving the solum, is quite high, (10.5 mg NO_3^- l^{-1} in 1989, compared to 3.4 mg NO_3^- l^{-1} in 1990). These are, of course, annual mean concentrations. The maximum permissable NO_3^- concentration in drinking water, according to EC standards, is 50 mg NO_3^- l^{-1}.

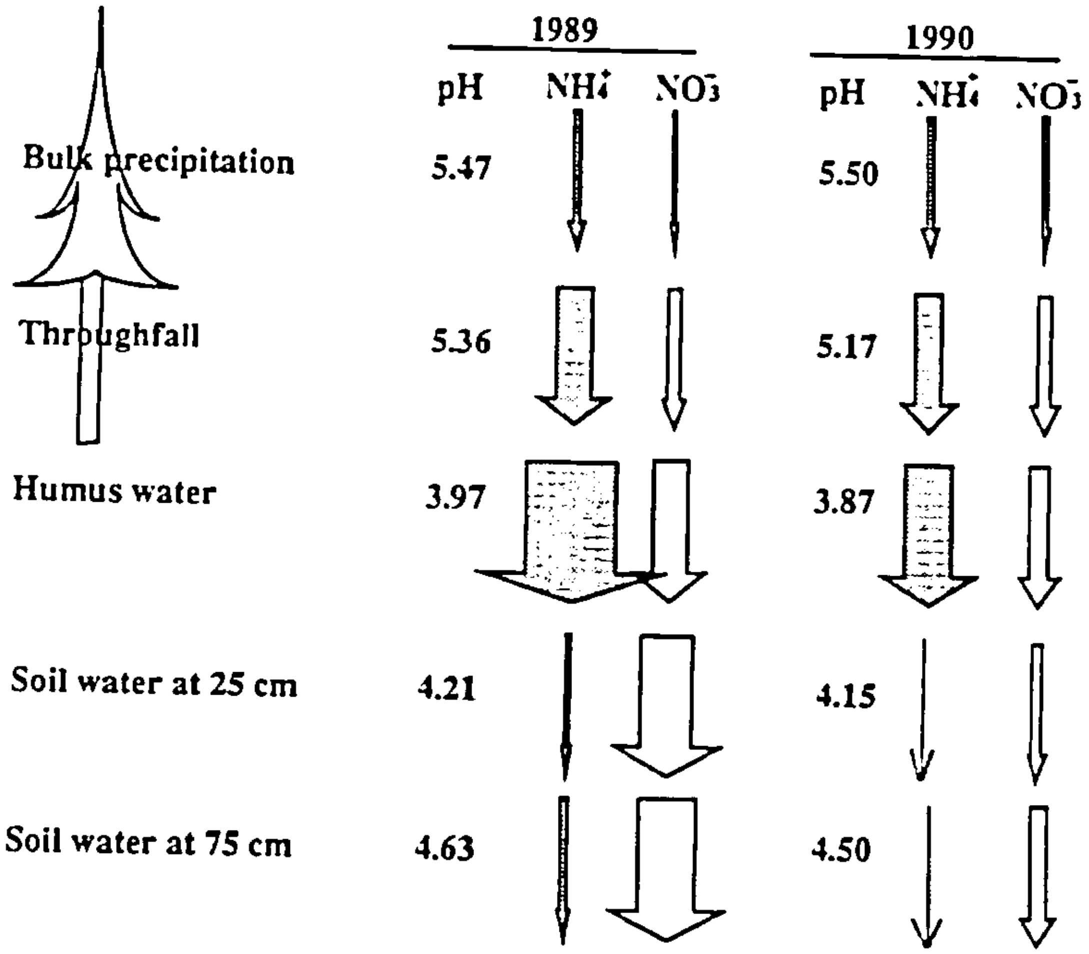

Figure 3 Mean ionic concentrations of nitrogen and pH in water from Ballyhooly (mmol$_c$l^{-1})1989, 1990

A study is presently underway at Ballyhooly to examine the relationship between slurry and fertilizer spreading and NH_4^+-N deposition in throughfall. Ballyhooly is the ideal site for a study on the impact of farming activity on forest ecosystems. The forest block is small with managed grassland on two sides (Figure 4). Local farmers cooperated in a preliminary survey conducted in 1990. The main farm enterprise is dairy production and while not highly intensive, several farms have animal housing units and both slurry and nitrogenous fertilizer are applied to the land. This moderate intensity of animal production, coupled with relatively low ambient atmospheric NH_3 concentrations, provide an opportunity to record the effect of spreading operations and grazing on atmospheric and rainfall chemistry within the boundaries of the forest.

In the preliminary survey, farmers whose land lay within 500 m of the forest were asked to record the date of each spreading operation, the type of material spread (slurry or the particular nitrogenous fertilizer) and the weather conditions at the time. The relationship which emerged from this rather crude survey between throughfall NH_4^+ and spreading activity is shown in Figure 5. While the value of this survey was limited, the data show clear evidence of locally produced NH_3, as evidenced by the coincidence of NH_4^+ peaks and high throughfall pH. It is intended to conduct a similar survey with more intensive monitoring of rainfall, throughfall, gas concentrations and weather conditions in 1992.

The HEAD gas collection was operated during the period of the survey, but for only two weeks, at the end of July and again at the end of September. The HEAD is located about 300 m south of the forest plot (Figure 4). NH_3 concentrations ranged from 0.73 ug m-3, over a 12 hour period during the night of September 30 to a four-hour morning peak of 6.52 ug m^{-3} in July. The annual average NH_3 concentration at the EXMAN site at Kootwijk in the Netherlands is 6.7 ug m^{-3} (Erisman and Heij 1991), with occasional much greater peaks. Daily concentrations of up to 250 g m^{-3} are measured in the Netherlands (Asman and Janssen 1987).

CONCLUSION

Of the gases emitted as a result of agricultural activity, NH_3 is the most important in terms of its immediate impact on forest ecosystems. It has been associated with visible damage to forest crops in some countries and it certainly contributes to soil acidification, nitrate leaching and nutrient imbalance.

There is, as yet, no evidence of forest damage in Ireland resulting from NH_3/NH_4^+ deposition. Widespread damage would certainly never be expected. However, local impacts should be monitored, particularly in relation to the interactive influence of animal production and forest ecosystems on water quality. Despite the fairly low level of average emissions, concentrations in areas of intensive animal production should be monitored and the health of nearby forests kept under observation.

Figure 4 Location of forest ecosystem monitoring site, Ballyhooly marked * and surrounding farms shown cross-hatched or shaded

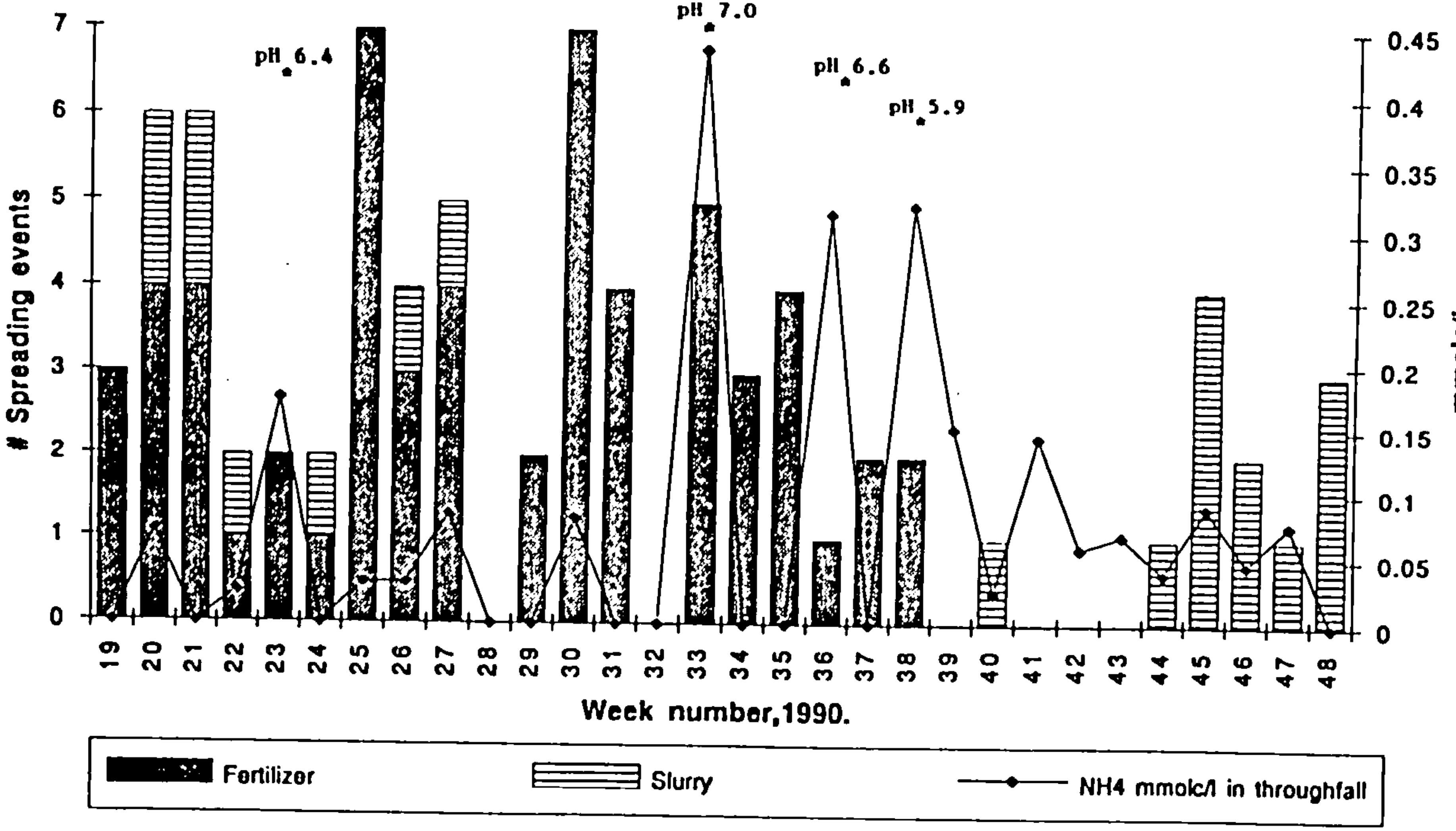

Figure 5. Relationship between fertilizer/slurry spreading and the chemistry of throughfall water at Ballyhooly

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IMPACT OF ENVIRONMENTAL AND CLIMATIC FACTORS ON FORAGE CONSERVATION PRACTICES

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ABSTRACT

Grass conservation practices in Ireland changed rapidly between 1960 and 1990 in line with the substantial increase in beef and dairy output. Hay was replaced by silage on intensive farms, with much of the silage being direct-cut and treated with an acid additive. Much of the impetus for these changes came from a need to achieve relative independence of weather conditions. Silage effluent production increased simultaneously. Due to further developments in technology, changes in net farm incomes and environmental considerations most silage is now cut and harvested in two separate operations, with much less acid additives being used. Big bale silage has become important on small farms and self-feeding silage has been largely replaced by easy feeding. Silage fermentation is still a relatively uncontrolled process and, even though our understanding of the principles controlling this process have improved considerably, particularly the specific effects of the mild and moist Irish climate, our ability to consistently produce a product of predictable nutritive value is unsatisfactory. Developments in the coming years should include practices to economically and reliably produce a high nutritive value conserved feedstuff, with minimal negative side-effects on the environment.

INTRODUCTION

Grassland accounts for over 90% of agricultural land use in Ireland and most of this consists of permanent swards of grass with a diverse botanical composition. Only about 3% of grassland is reseeded annually (Keating and O'Kiely, 1990). In excess of 90% of the feed intake of ruminants comes from grazed or conserved grass. Due to the seasonality of grass growth and with the poor load-carrying capacity of soils in winter, surplus grass produced during the summer is conserved and fed to housed animals during the winter. The duration of feeding conserved forages indoors ranges from 3 to 6 months, so the dependence on conserved feeds in intensive livestock systems is significant. Silage has replaced hay as the form in which grass is conserved on intensive farms, and nationally silage now accounts for about 75% of total conserved grass.

CHOICE OF CROP

Grass is a flexible, durable, easily managed crop that can support high levels of animal performance at a modest cost. As shown in Table 1 (Keane, 1988), the grass growing season (*i.e.* when air temperature is above 5.6°C) is quite long in Ireland and this, together with the relatively high rates of grass growth throughout the season, indicate that temperate grasses are particularly suited to the Irish climate. Conversely, the data in Table 1 also show that crops such as maize and lucerne are less suited to the Irish climate than to other European sites.

TABLE 1. Duration (weeks) of the growing season in inland NW Europe.

Threshold temperature	Ireland Kilkenny	England Cambridge	France Le Mans	Netherlands De Bilt	Germany Hannover	Denmark Strommen
5.6°C	40	38	40	35	33	30
10°C	24	25	28	25	24	20
15°C	5	15	17	13	13	10

Source : Keane 1988

METHOD OF CONSERVATION

Grass is conserved as hay by sufficient water being evaporated off to render the plant enzymes inactive and to reduce the water activity (increase osmotic pressure) sufficiently to prevent microbial activity. Silage is conserved by achieving anaerobic conditions to terminate aerobic losses and by reducing pH by lactic acid production to inhibit the activity of undesirable anaerobic micro-organisms. Wilted silage is preserved by a combination of reduced water activity, anaerobiosis and reduced pH. The more rapidly any of these conservation processes are carried out the greater the opportunity to minimise losses and retain maximum feeding value. The reasons why Irish farmers switched from hay to silage, with a preference for silage-making systems that depended very little on any field drying, was due to the general unsuitability and unreliability of the Irish climate to conservation systems that depended on field drying. This is particularly clear from the climatic data presented by Keane (1988) which showed relatively modest solar radiation and incidence of consecutive rain-free days in Ireland, together with great variability within and between years. This, together with high humidity (Thran and Broekhuizen, 1965) makes field-drying of grass unreliable, and at best, opportunistic.

Rate of decline in digestibility

As grass develops from the vegetative to inflorescence phases, the proportion of leaf decreases, lignification increases and the digestibility declines. This process is initiated by day-length (Jones, 1988) and therefore tends to be somewhat predictable from year to year. However the rate of digestibility decline can be altered - drought causes the proportion of leaf to decrease more rapidly (Jones, 1988) while high temperatures increase the rate of lignification and the rate of senescence of the lower leaves (Deinum, 1984). Severe crop lodging during wet weather also increases the rate of decline in digestibility (O'Kiely *et al.* 1987). Experiments are in progress at Grange to determine if grass growth during mild winters and springs reduces the digestibility of meadows in late May due to the accumulation of dead vegetation at the base of the crop.

Water-soluble carbohydrates (WSC)

Non-structural carbohydrates such as glucose, fructose, sucrose and fructans, which are soluble in cold water, are energy sources for lactic acid bacteria during silage fermentation. The amount of WSC present in the grass at harvesting is critical, since sufficient lactic acid must be produced during fermentation to reduce the pH from about 6.0 to approximately 4.0. The WSC content is a balance between the sugars anabolised during photosynthesis and those catabolised during respiration or used for growth. Temperature has an effect on this balance, with lower temperatures tending to restrict respiration more than photosynthesis, the result being that WSC levels increase (Deinum, 1984). Solar radiation correlates possitively with grass WSC values (Deinum, 1984). Deinum's studies therefore suggest that WSC levels in grass DM are highest when plants are grown at high light intensities and low temperature and lowest in shade and high temperature. McGrath (1988) has shown that within WSC the balance of individual sugars is influenced by both season and climate.

Grass WSC, expressed as g l^{-1} aqueous phase, vary considerably. Weather, together with grass species/cultivar and fertiliser have a major effect, while season, physiological growth stage and time of day have lesser effects. The major diurnal effect is that of dew. Rainfall, by wetting the crop, clearly lowers the WSC content in the aqueous phase. Consequently, if a crop of 200 g dry matter (DM)kg^{-1} and 150 g WSC kg^{-1} DM were rained on such as to reduce its DM content to 170 g kg^{-1} or 140 g kg^{-1} the WSC content in the aqueous phase would decrease from 37.5 g l^{-1} to 30.7 or 24.4 g l^{-1}, respectively.

Figure 1 demonstrates the variation in grass WSC during May to July in successive years, when both the crop and management practices were constant (O'Kiely *et al.*, 1987). Most of this variation was weather related, tending to decrease during wet, overcast, warm conditions. If 30 g WSC l^{-1} is taken as a threshold above which the grass should be relatively easy to preserve as silage, the ensilability of grass was very variable and was strongly influenced by weather. However, the entire fermentation process can interact with ambient temperature. O'Kiely (1991 - unpublished data) has shown that by

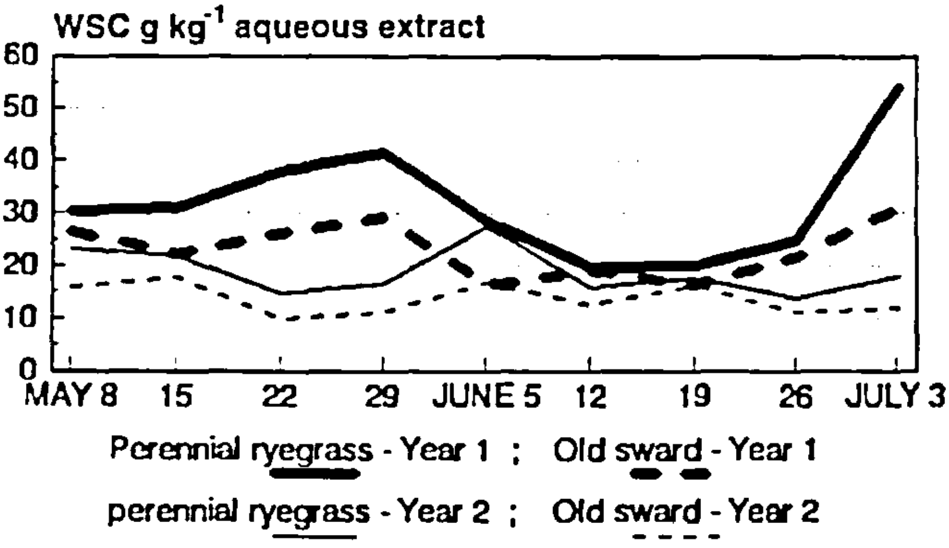

Figure 1. WSC in primary growth of *Lolium perenne* and an old permanent grassland sward in two successive years. O'Kiely *et al* (1987).

increasing the ambient temperature at which autumn harvested grass was stored during ensilage from °C to 18°C, mean silage pH, ethanol, acetic acid and propionic acid levels increased from 4.2 to 4.7, 25 to 70 g kg^{-1} DM, 21 to 91g kg^{-1} DM and 0.4 to 8.5 g kg^{-1} DM respectively, while lactic acid decreased from 83 to 19 g kg^{-1} DM. This difference probably reflects the dominance of Enterobacteria rather than lactic acid bacteria due to the changed environmental conditions in that experiment.

Buffering capacity

The buffering capacity of grass is its ability to resist a change in pH and is expressed as milli equivalents (m.eq)kg^{-1} DM required to reduce the pH from 6.0 to 4.0. It can be quite variable in grass and is influenced by protein, organic acids, chlorides, orthophosphates, nitrates ita. (Muck, O'Kiely and Wilson, 1991a and b). It tends to decrease as grass advances into the inflorescence phase (Muck *et al.*, 1991a) but can also be influenced by grass species/cultivar, fertiliser and weather. Values for the primary growth and subsequent summer regrowths start at 400 to 450 m.eq.kg^{-1} DM and decline linearly by about 20 m.eq.kg^{-1} DM per week. Buffering capacities remain high in autumn grasses (Muck *et al.*, 1991a). Muck and Walgenbach (1985) showed that buffering capacities in alfalfa are higher in leaf than stem and decrease more rapidly in stem than in leaf. Consequently, climatic influences on the leaf to stem ratio could indirectly influence buffering capacity. The data of Muck and Walgenbach (1985) also suggest that the uptake of Zn, Fe, Cu and Al, and to a lesser extent K and Mn, increases buffering capacity - their uptake could also be related to climatic conditions.

Microflora

The lactic acid bacteria of most importance in silage production include Lactobacillus, Pediococcus, Streptococcus and Leuconostocs. Moran and O'Kiely (1989) monitored counts of total lactic acid bacteria (LAB) on grass grown for silage between May and September. Much higher counts were obtained in Ireland (5.50 $\log_{10}$ colony forming units (CFU)g^{-1} grass; s.d. 1.26) (Moran and O'Kiely, 1989) than in many other countries (Pahlow, 1991). This was attributed by Moran and co-workers to the lower influx of UV radiation, the higher humidity and less variable temperature than other countries, as well as to the dense crops of grass grown for silage. In addition, Pahlow (1991) has proposed that in Ireland LAB are less likely to enter a somnicell *i.e.* dormant phase as a result of stress caused by climatic conditions than in other countries, thereby explaining the higher counts of viable LAB cells found on Irish grasses. However, the O'Kiely (1989 - unpublished data) has found very low LAB counts on grass very dry and sunny weather in a very sparse crop.

Clostridia and Enterobacteria are two of the main undesirable bacteria found in silage. Soil and animal manures are the main sources of inoculation. With good silage-making practice their effects should be reduced. Nevertheless, to permit efficient recycling of nutrients, slurry is normally spread on the bare grass stubble. In the absence of rainfall in the days after spreading, the likelihood of contamination carrying through to harvesting is increased. This is shown in Table 2 where the increased content of butyric acid suggests the activity of saccharolytic clostridia.

TABLE 2. Silage fermentation when cattle slurry is applied by different techniques.

	Slurry application			
	None	Splash-plate	Bandspread	Shallow injection
Lactic acid g kg $^{-1}$ DM	86	93	101	75
Acetic acid g kg $^{-1}$ DM	18	14	20	19
Butyric acid g kg $^{-1}$ DM	0	12	3	1
pH	3.94	4.01	3.94	3.93

Source : O'Kiely and Carton (1990).

Field drying

Solar radiation, in the form of radiant energy incident on the crop, is the primary driving force for moisture evaporation. Drying rate is also influenced by the temperature and the humidity of the ambient air (vapour pressure deficit), moisture content of the soil and thickness of the swath. Mechanical and chemical treatments can speed field-curing under good drying conditions, but they cannot compensate for poor drying weather, (Bolsen, Brent and Dickerson 1991). The time required to dry alfalfa from 80% down to 20% moisture, under constant weather conditions (Rotz and Chen, 1985) ranges from 12 to 48 hours. (Table 3) Because environmental conditions rarely remain constant, particularly when the drying period extends overnight, actual field-curing times are longer. They would be considerably slower if weather conditions were wet. The climatic data presented by Keane (1988) clearly shows the unsuitability of the Irish climate for producing quality hay by field drying.

TABLE 3. Hours to dry alfalfa from 80 to 20% moisture in constant weather conditions.

		Air temperature°C				
Weather[1]	Soil conditions[2]	10	15.6	21.1	26.7	32.2
Cloudy	Wet	44	41	38	35	33
Cloudy	Dry	36	34	31	29	27
Sunny	Wet	16	16	15	15	15
Sunny	Dry	14	13	13	12	12

[1] Cloudy = 100 Btu/hr-ft^2 solar radiation; sunny = 280 Btu/hr-ft^2 solar radiation.

[2] Wet = 20% moisture content; dry = 9% moisture content.

Source : Rotz and Chen (1985).

Partial field drying of grass is sometimes used prior to ensiling as a mechanism to reduce, or prevent, effluent production and to facilitate good preservation. The mean dry matter (DM) contents of grass at cutting or after 6 or 24 hours wilting in 13 experiments at Grange between 1980 and 1985 was 208, 223 and 268 g DM kg^{-1}, respectively. In each case wilting conditions were good. Simultaneously, wilting experiments planned for preselected dates were postponed on 15 occasions due to wet weather and on four other occasions wilting was attempted and failed. In a separate series of experiments where field wilting was carried out, it was shown that tedding grass to achieve full ground cover together with frequent turning is essential to maximise drying rates (Table 4). Rain reduces DM and WSC concentrations more when it falls on an uncut rather than a mown crop (O'Kiely, 1988,1989a).

TABLE 4. Mean effects of wilting on grass DM and WSC contents

Time	0 hrs	6 hours				24 hours				30 hours			
Treatment		1	2	3	4	1	2	3	4	1	2	3	4
						Dry matter g kg^{-1}							
- mean	197	214	236	264	264	200	267	301	329	222	330	388	473
- s.d.	37.3	43.1	53.0	60.5	65.1	31.7	66.5	77.7	93.5	38.7	99.5	110.3	121.9
						WSC g kg^{-1} juice							
- mean	29	34	38	46	48	29	45	58	63	34	66	83	92
- s.d.	11.4	11.3	13.8	18.0	20.1	7.6	16.4	26.2	29.1	11.7	30.7	37.4	35.0

Treatments 1 through 4 were: 1) standing crop, uncut, 2) mown and untedded, 3) mown and tedded once (at cutting) and 4) mown, tedded immediately and after 6 and 24 hours. **Source :** O'Kiely (1988,1989a).

Additives

The type of silage additive recommended, if any, is strongly influenced by weather conditions, with preservatives such as acid or sugar additives being preferred where ensiling conditions are difficult and inoculants of LAB where ensiling conditions are good. Whatever additive is used, the application rate is expressed per tonne harvested grass. In the absence of weighing facilities on farms, the rate of harvesting is difficult to identify when expressed as tonnes/hour but not when expressed as hectares/hour. However, as a crop gets wetter during rain the yield of fresh grass per hectare can readily rise by 60%, thereby necessitating a corresponding increase in additive application. This adjustment is rarely done in farm practice

The use of acid additives, which are very effective preservatives, has decreased considerably in the past 3 years due to the danger they represent to operatives and the corrosion caused to machinery.

Rate of achieving anaerobiosis

When anaerobic conditions are achieved quickly after harvesting, good preservation (Wilson and Flynn, 1979) as well as enhanced aerobic stability at feeding time (Honig 1991), are facilitated. Very wet weather at harvesting can interfere with the speed with which the silo is filled.

Aerobic deterioration

Since ensiling is by necessity an anaerobic process, silage, once it comes in contact with air at feeding time, is inherently unstable. Silages vary enormously in their instability when exposed to air, the rate of deterioration depending on management factors (based on minimising the duration of exposure to air), weather and silage microbiological, physical and chemical composition (O'Kiely, 1989). Higher ambient temperatures increase the rate of aerobic deterioration of silage (Table 5) as do dark and humid conditions (O'Kiely, 1988/89b).

TABLE 5. Effect of ambient temperature on aerobic deterioration.

	Ambient temperature	
	10°C	25°C
Number of experiments	84	84
DM loss g kg^{-1}	26	269
Days to pH rise	9.9	5.8
Days to temperature rise	9.5	3.1
Accumulated temperature rise (degree days)	12	105

Source : O'Kiely (1989)

SILAGE EFFLUENT

Parallel to the increase in silage production has been an increase in the volume of silage effluent produced. Among the disadvantages associated with effluent are the pollution caused if it enters surface or ground water, corrosion of concrete, cost and inconvenience of collecting and disposing it and the loss of harvested nutrients.

Silage effluent has a typical BOD of 50000 to 80000 mg O_2 l^{-1}; and this is quite high compared to materials such as domestic sewage (200 to 500 mg O_2 l^{-1}). Pollution ensues when effluent enters freshwater due the growth of micro-organisms stimulated by the high content of soluble organic matter and minerals in effluent. Clean effluent itself is not toxic to livestock. It only becomes a pollutant when "it goes where it is not meant to".

Volume of effluent

The volume of effluent produced when grass is ensiled is very variable and can range from none to over 300 litres per tonne. Grass dry matter (DM) content is the chief factor determining the volume produced - the wetter the grass the greater the volume of effluent (Table 6). Increasing the degree of compaction in a silo also increases the volume of effluent, whereas silage harvester type *per se* has relative little effect. The amount of effluent leaving silage and entering collection channels is obviously reduced by leakage through cracked or corroded floors or walls. Such leakage would have serious consequences from the points of view of both pollution and the structural integrity of the silo, and must be prevented at all costs.

TABLE 6. Estimated effects of grass DM content and vertical pressure on effluent production $l\ t^{-1}$ grass.

	Grass DM content g kg^{-1}							
	140	160	180	200	220	240	260	280
Silage height m	l effluent t^{-1}							
1	150	110	60	10	0	0	0	0
3	300	250	210	160	120	70	20	0

Source : Weissbach and Peters (1983).

The use of different silage additives also affects effluent production. When grass, treated with additives, was ensiled in laboratory silos with good drainage facilities, the total volume of effluent produced during an extended storage period (more than 100 days) was not altered much by normal application rates of acid additives, molasses or inoculants (Table 7). On the other hand, large inputs of fibrolytic enzymes did increase total effluent production. This was probably related to the breakdown of fibre in these silages and the consequent reduction in the forages' capacity to retain effluent. Dry materials (absorbents) are sometimes ensiled with grass with the intention of reducing effluent production. Whereas many of them have the capacity to absorb impressive amounts of effluent, their capacity to retain effluent under the physical and chemical conditions in a silo is usually much less impressive. The values summarised in Table 8 indicate that very high levels of absorbent addition are necessary to retain the normal levels of effluent produced with direct-cut grass (average of 140 litres/tonne).

TABLE 7. Mean volumes ($l\ t^{-1}$ grass) of effluent produced with different additive treatments

No additive	Formic acid	Molasses	Inoculant	Fibrolytic enzymes	SEM[1]	Sig.	n[2]
170 (75.5)[3]	178(71.6)				2.8	NS	28
139 (67.2)	137(65.7)	130 (60.5)			4.5	NS	10
167 (69.1)	167(72.7)		170 (76.0)[4]		3.9	NS	12
106 (80.6)	113(72.7)		108 (86.7)[5]		6.5	NS	7
160 (64.9)	159(65.9)			208 (87.6)	5.5	***	16

[1]Standard error of the mean; [2]Number of experiments averaged; [3]Standard deviation among experiment means; [4] and [5]Commercial inoculants without (4) or with (5) fibrolytic enzyme inclusion. NOTE : Each treatment was replicated 4 times in each experiment.

Source : O'Kiely (1990).

TABLE 8. Grouping of different absorbents ensiled with grass according to their retention capacities

Retention rates, kg effluent kg $^{-1}$ absorbent

Less than 1.0	1.0 to 2.0	Over 2.5
Barley Corn gluten Dried distillers grains Soyabean meal	Dried beet pulp Malt culms	Straw

^{1} 2 m high silos. Source : O'Kiely (1990).

Controlling effluent

(a) **Ensile drier grass.** Wilting (partial field drying) grass to increase its DM content to 300 g kg^{-1} and thereby eliminate effluent production is often attempted under Irish conditions. However, it is frequently not possible to wilt due to wet weather. Wilting can lead to loss of silage nutritive value (O'Kiely, Flynn and Wilson, 1988), but some farmers will accept this to avoid producing effluent.

Chemical treatment of the grass with dessicants such as formic acid (Jones, 1990), diquat and glyphosate have been of limited practical benefit. On the other hand potassium carbonate and sodium carbonate are successful dessicants with legumes (Rotz and Thomas, 1983) but not with grasses (Verma *et al.*, 1986).

The concept of dewatering grass in the field has received attention by Koegal *et al* (1988) in the US. However, rainfall on partially dewatered grass would lead to large losses. Pneumatic removal of water from the surface of wet grass is a concept worth attention. There is not sufficient information to quantify the effect of grass species or cultivar on effluent production.

(b) **Retain effluent within the silo.** It is neither possible nor desirable to seal effluent in conventional silos. However, bagged big bale silage can prevent effluent loss. Less compaction, as in baled silage, reduces effluent production, but is impractical with conventional silos. It is possible to retain effluent within the silo by ensiling dry products (absorbents) with the grass, but high rates of addition are usually necessary (Table 8). New chemical approaches to improving the nutritive value of dry forage using alkaline hydrogen peroxide have the side effect of increasing the water-holding capacity of the forage (Gould, 1985), but this effect may not be transferrable to wet forages.

(c) **Collect and use effluent.** This is the most realistic approach, in the absence of wilting, and must always be an option. The judicious land-spreading of effluent onto bare grassland is the best method of disposal and the effluent has a small fertiliser value.

The opportunity exists to reduce the volume to be spread and to realise the feed value of the effluent by feeding it to livestock. Good quality effluent is quite acceptable to cattle. Animals with *ad libitum* access to effluent can consume 15 to 30 litres per head daily and this has been reflected in improved animal performance (18 l effluent equivalent in nutritive value to 1 kg barley). However, on very many farms effluent feeding is impractical.

Dunlea and Dodd (1987) used reverse osmosis to separate effluent into its water and DM components. They demonstrated a 75 to 85% reduction in COD was possible, but that due to a very low permeate flux, the effluent could not be rendered a non-pollutant using the available technology.
Colleran (1988) reported on the digestion of silage effluent by upward progression in anaerobic filters. Even though it was shown that biogas was produced and the organic pollution potential of effluent reduced, the residue still presented a pollution threat, if only due to its high inorganic nutrient component.

CONCLUSIONS

Forage conservation practices have changed considerably during the past 30 years in line with the intensification of agriculture and the availability of new technologies. These were modified by effects of the mild and moist Irish climate and the economic situations on farms. The changes, which are ongoing, are now being additionally influenced by environmental considerations, labour reduction, ceilings on agricultural output and deteriorating agricultural profits.

Grass is still the primary crop ensiled, and is likely to remain so, although whole crop fodder beet (O'Kiely, Moloney and Meagher, 1991), whole crop barley (O'Kiely and Moloney, 1991) and maize (Keane, 1988) have also been considered. The latter can be grown successfully on some farms near the south coast, but new varieties are needed before the crop can be reliably grown elsewhere.

The very variable Irish climate makes it difficult in farm practice to reliably produce consistent quality silage. With decreasing farm profits and the expected drop in the relative price of concentrates compared to forages envisaged under the proposed CAP reforms, the attractiveness of silage will diminish unless this problem of variability can be overcome. Research by Teagasc at Grange has identified a series of guidelines by which this can be achieved. It is essential when formulating a set of guidelines for making grass silage of consistent quality, that the influences of climate on each component of silage production, and on the interactions between them, are fully understood. The impacts of climatic factors on some of these components are summarised below:

Digestibility - initiation of decline in the primary growth of grass is controlled mainly by day-length. However, the rate of decline can be accelerated by stress factors such as drought, high temperature or lodging in very wet weather. In addition, extensive growth during mild winters or springs or lodging prior to harvest may lead to the accumulation of dead vegetation in the crop base by late May - this may further reduce digestibility. Ensiling very wet grass may lead to increased losses of digestible material due to high effluent production, thereby reducing silage digestibility.

Preservation - the ideal weather to facilitate silage preservation is warm, sunny days and cool, dry nights in the week prior to harvesting. This combination encourages adequate

WSC levels in relatively dry grass, reduces the likelihood of soil contamination and facilitates fast filling and quick sealing of the silo. Animal manures should only be spread on bare stubble, especially during dry weather, and nitrogenous fertilisers should have at least a 6 week growth interval between application and harvesting.
Field drying (wilting) - drying rates are increased primarily by high rates of interception of radiant energy. This is facilitated during long, sunny days and by spreading (tedding) the drying crop to give it full ground-cover. High temperature and low humidity of the ambient air and low soil moisture contents encourage rapid drying rates. Rainfall, and to a lesser extent dew, slow or even reverse the drying rate.

Aerobic deterioration (at feeding) - depends on the duration of access to oxygen by silage (regulated by management factors) as well as on the inherent stability characteristics of the silage. Silages are aerobically more unstable in warm weather. High humidities and low UV radiation accentuate the problem.

Effluent Rainfall in the days prior to and during harvesting is the major climatic factor influencing effluent production.

Precision-chop and big bale silage, both of which involve separate cutting and harvesting operations, are replacing the traditional single and double-chop direct-cut systems (Power, 1991 - unpublished data). This increases the opportunity to produce wilted silage, and is also diminishing the attractiveness of acid preservatives. However, the latter still have an important role to play in consistently producing well preserved silages.

Collection and landspreading of silage effluent, spreading animal manures on silage aftermath and the input of high levels of artificial fertiliser on silage ground must be carried out judiciously, taking full account of the immediate climatic conditions, to prevent undesirable effects on the environment. Otherwise severe restrictions may be imposed in the future.

Hay production, which is inherently unsuited to the Irish climate, is unlikely to increase in quantity in the forseeable future.

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OBSERVATIONS ON THE POSSIBLE INFLUENCE OF CLIMATIC CONDITIONS ON RESPIRATORY DISEASE OUTBREAKS IN INTENSIVELY HOUSED CATTLE

(SHORT COMMUNICATION)

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Respiratory disease is a cause of major financial losses in housed cattle (Alexander, MacVean and Salman, 1989 ; Jensen and Mackey, 1979).

Serological studies on cattle in intensively housed conditions indicated that viruses may circulate in such populations in Ireland without causing clinical disease (Gunn, personal observation).

In increased number of outbreaks of respiratory disease in feed lot cattle during the 1989 - 1990 winter season in comparison to other seasons and the association of different viruses, either singly or in combination, with outbreaks (Gunn and Wilson, 1991) prompted consideration of possible environmental factors which may be associated with, or predispose cattle to, respiratory disease when housed.

Records of climatological factors such as relative humidity, maximum and minimum temperature and windspeed for an area where a large number of such outbreaks occurred (during the 1989/1990 winter period) were obtained from the Meteorological Service at Glasnevin, Dublin. Data, for the period of six weeks prior to the outbreaks to the end of the outbreaks, were analyzed and compared with measurements from previous years which did not have such high submission rates. The only values that were characteristically different were those for mean daily windspeed for a spell at the end of November and beginning of December (Fig. 1). This period encompassed or preceded a period when a large number of outbreaks occurred.

Low grade circulation of viruses among groups of cattle or reactivation of viruses in individuals or groups are the main sources of respiratory viral infections in cattle (Splitter, Eska, Miller-Edge and Splitter, 1985 ; Fenner, Bachmann, Gibbs, Murphy, Studdert and White, 1987). As a general concept the higher the concentration of viral particles that an animal is exposed to the greater the possibility of disease. Housing systems should aim to reduce the concentration of viruses excreted from the respiratory tract, from the immediate environment of the animals. While air change rates for cattle housing have traditionally considered such items as temperature control, indicators of dust or spore levels, carbon dioxide elimination *etc.*, it is desirable that they should also consider reducing viral pathogens in the environment. A minimum ventilation rate, which is independent of windspeed, should be adequate to prevent a large build up of viral particles in the air surrounding the cattle.

The principles of ventilation in purpose-built cattle sheds are shown in figure 2 which indicates the direction of ventilatory air flow during periods of minimum windspeed. This convection based system is based on heat generation by the cattle. The principle governing this type of ventilatory system is described by the equation (Fig 3) derived by

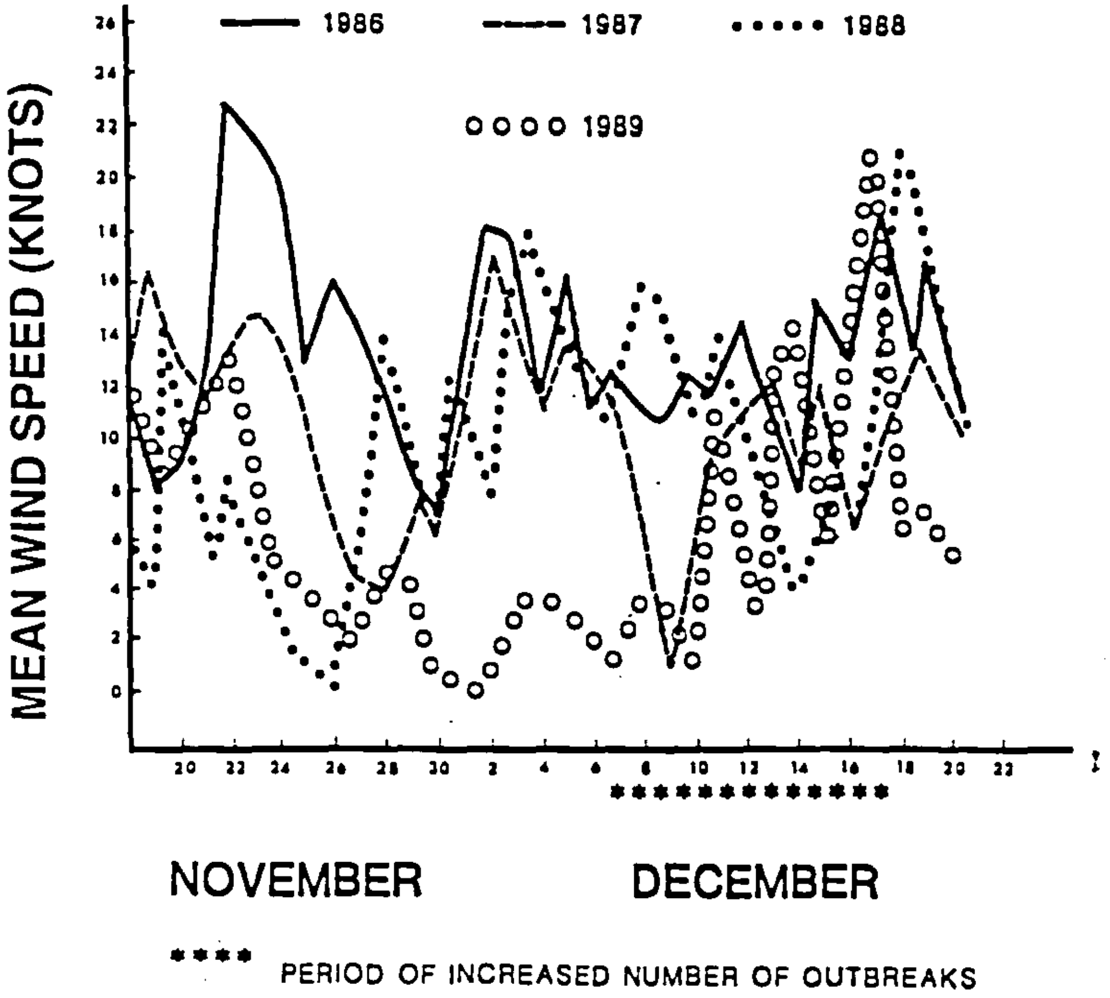

Figure 1. Mean daily windspeed for the November/December periods of 1986 to 1989 inclusive.

Bruce (1978) which encompasses the structural design of cattle sheds and the differential temperature between the inside and outside of the shed. Assuming that the air inlet and outlet areas, and the differential height between the inlets and outlets are optimal, the main determining factor for the working of the convection based ventilation system during periods of minimal windspeed is the differential temperature between where the cattle are kept and the outside of the shed. Within limits the higher the differential temperature the higher the air change rate. A differential temperature of 5.5°C when the outside temperature was 1°C gave an air change rate of 16 per hour in the custom built cattle shed. (V. Dodd and M. Gunn personal observations). A differential temperature of 3°C was recorded when the mean outside temperature was 6°C. During periods of minimal windspeed and such temperatures lower air change rates than 16 per hour would be experienced by stock in such a shed.

As the mean daily outdoor temperatures for the period in question in 1989 were not obviously different from previous years and varied between 4 and 8°C (mean 6.6°C), it is probable that reduced windspeed for a period of time may in itself be sufficient to limit adequate ventilation in the sheds and be associated with a build up of respiratory viruses in the environment.

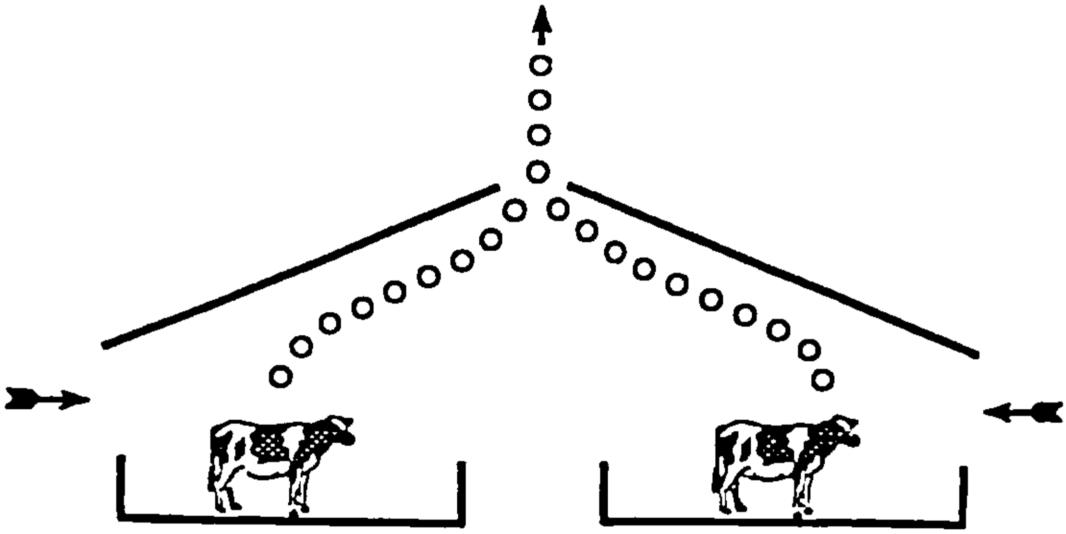

Figure 2. Outline of natural ventilation in a purpose built beef unit

$$Q = CA1\left[2G\,\frac{dT}{T} \times \frac{H}{1+\left(\frac{A1}{A2}\right)^{2}}\right]^{1/2}$$

Q = Ventilation rate (M^3/Sec/M)
C = 0.6
G = 9.81
dT = Difference in temperature between inside and outside the shed.
T = Average temperature (degrees absolute)
H = Effective height (midpoint of inlet to outlet height)
A1 = Inlet area.
A2 = Outlet area.

Figure 3. The principles governing natural ventilation in a purpose built cattle shed with two openings on the horizontal plane. From:- Bruce (1978)

Whether a build up of viruses in the environment within the sheds may lead to a disease outbreak will depend on the initial amount of viruses being excreted by "index" animals, the prior exposure of other animals entering the shed to the pathogens as well as the rate of build-up of infectious particles to cause an outbreak has yet to be determined. Nevertheless it may be possible to predict periods of low windspeeds during the early winter period (soon after cattle enter the sheds) and thus identify a risk factor which predisposes animals to respiratory disease when housed. Farmers may then be in a position to take prophylactic measures.

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METEOROLOGICAL FEATURES ASSOCIATED WITH OUTBREAKS OF BOVINE HERPES MAMMILLITIS IN IRELAND

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INTRODUCTION

Bovine herpes mammillitis (BHM) is an ulcerative disease which affects the teats and sometimes the udders of heifers and cows. It occurs most commonly in heifers within a few days of calving, though animals at all stages of lactation, and even in-calf and younger heifers can be affected in extensive outbreaks. Usually the first cases in an outbreak, often in high-yielding heifers with physiological udder oedema, are the most severe.

Bovine herpes mammillitis is caused by bovine herpesvirus 2 (BHV 2). Following primary infection, BHV 2, like most herpesviruses, can become latent, and may be reactivated by stress or the administration of corticosteroids. The first isolation of BHV 2 in Ireland was made in 1978.

Antibody is present in nearly all cattle populations, suggesting that many infections are subclinical or mild. Antibody is present in calves, yearlings, maiden heifers, bulls and 17% of cows. At least 19% of herds in Ireland have some positive animals.

The occurrence of BHM in the second half of the year, often in localised epizootics, suggests that weather may exert an influence on outbreaks. The small number of reports on the weather associated with BHM are mainly anecdotal, and are mostly confined to conditions immediately preceding and during outbreaks. This communication reports the investigation of meteorological features occurring throughout two consecutive years when the number of BHM outbreaks are considerably increased in Ireland.

Materials and Methods

Virology/serology. A total of 23 suspected outbreaks were investigated by the Veterinary Research Laboratory since 1978.

Meteorological features. The following information was provided by the AGMET division of the Meteorological service (1) Poulter Indices of summer weather for approximately the last 100 years. The Poulter Index is derived using temperature, rainfall and sunshine duration for the months of June, July and August. (2) Meteorological data from the Roches' Point synoptic weather station comprising monthly minimum, maximum and mean temperatures, windspeed and total rainfall values for 1979-1989.

Rain/windchill factor (RW). The monthly rain/windchill factor for each year was calculated from the windspeed, air temperature and rainfall values (McIllroy and others, 1989, Vet Record 125, 79-82) using a constant relative humidity value of 80%.

Grass growth. Monthly grass growth records for 1982 to 1990 were obtained from Teagasc, Moorepark Research Centre, Fermoy, Co. Cork. Experimental results on the use of grass/clover swards for cattle grazing were obtained from Teagasc, Johnstown Castle Research Centre, Wexford.

Statistical analysis. The significance of the difference of monthly and annual values from the mean was assessed using the 2-tailed t-test.

Results and Discussion

Virology/serology/outbreaks. Clinical outbreaks of BHM were confirmed by viral isolation and/or antibody detection on 19 occasions. The monthly and yearly occurrence of outbreaks is shown in figures 1 and 2. Seven outbreaks were recorded in both 1985 and 1986, mainly in County Cork.

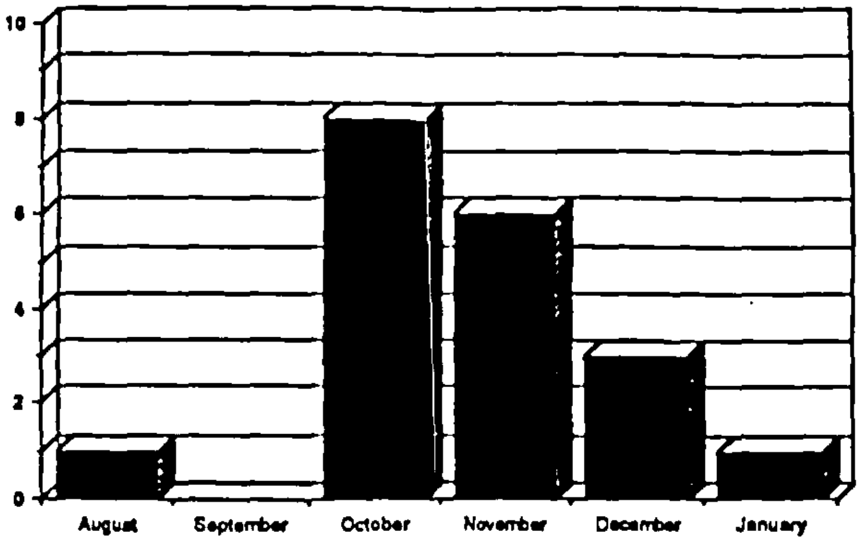


Figure 1. Monthly occurrence of outbreaks of BHM in Ireland. 1978 - 1991

Figure 2. Yearly occurrence of outbreaks of BHM in Ireland. 1978 - 1991

Poulter Index

Table 1 shows the Poulter Index for 1985 and 1986, together with the 11 year and 100 year mean. A lower Poulter Index than that obtained in 1985 and 1986 was only recorded once (1912) at Birr, four times (1912, 1922, 1924 and 1980) at Valentia and twice (1912 and 1980) at Dublin during the last 95-107 years. Both summers were extremely wet, cold and dull, with 1985 being the wettest summer at many locations since records began. No suspected cases of BHM were reported to the laboratory during 1980, so it is probable that additional factors are involved in BHM outbreaks.

Table 1. Poulter Index of Summer Weather

Location	**100 Years Approx.** (95-107 years) **Mean**	**Mean 1979 - 1989** (+s.d)	**1985**	**1986**
Birr	329	317 (42.7)	249^{a-}	262^{b-}
Valentia	361	347 (46)	281^{a-}	303^{b-}
Dublin	344	332 (39.0)	291^{b-}	278^{a-}

Significance of difference from mean: a = $p<0.001$,
b = $p<0.01$,
- = below mean.

Temperature, windspeed, rainfall

Figure 3 shows the monthly deviation from mean temperature, windspeed and rainfall values during 1985 and 1986 and the statistical significance of the difference from the mean. August was the only month with significant deviation from all meteorological features in both years, *i.e.* in both 1985 and 1986 it was significantly colder, windier and wetter than the monthly mean. The lowest absolute minimum temperature, lowest mean maximum temperature, lowest mean temperature, highest windspeed and highest rainfall for August occurred in 1985 and 1986.

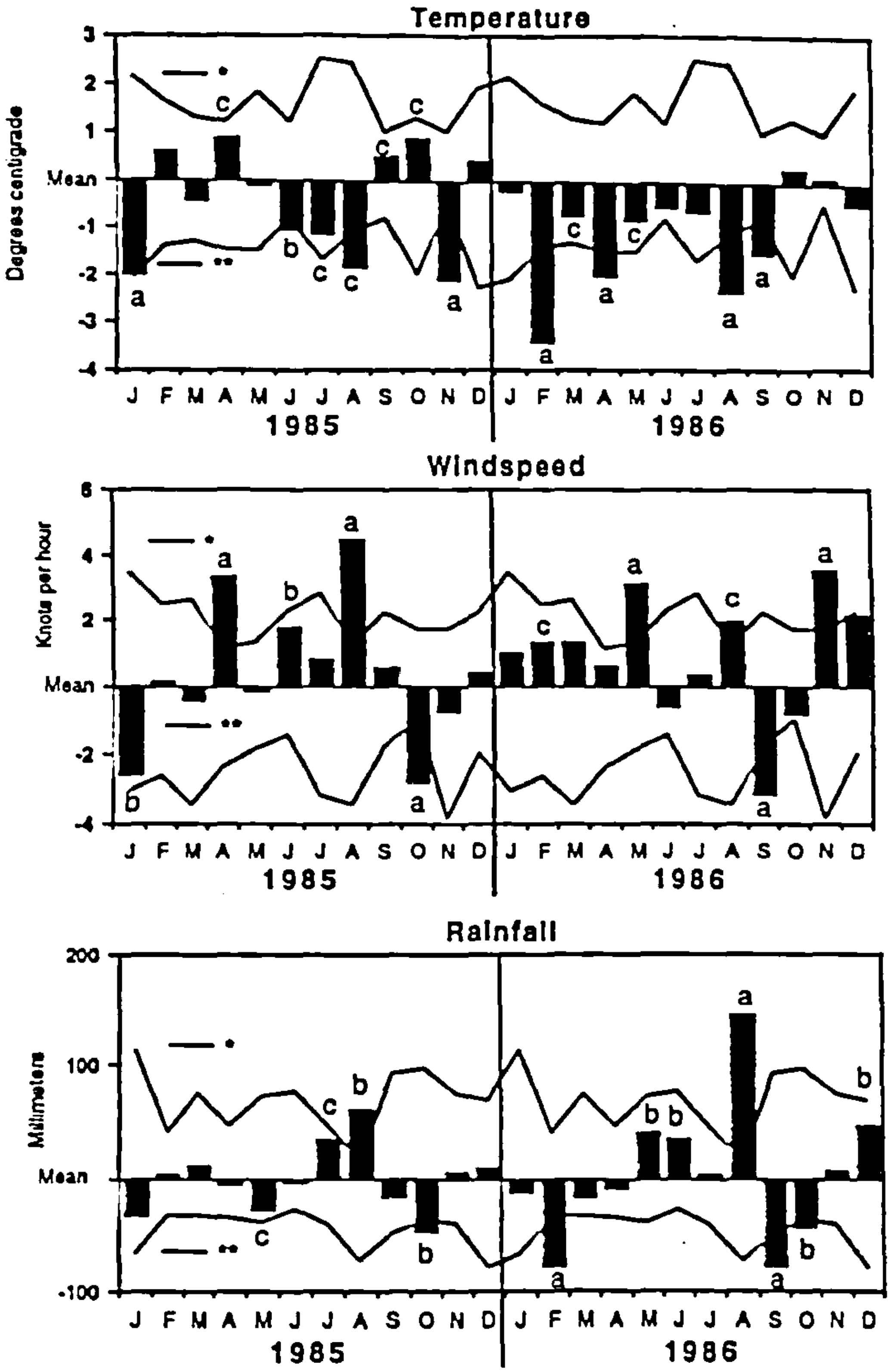


Figure 3. Deviation from mean monthly temperature, windspeed and rainfall during 1985 & 1986.

Significance of difference from mean: a = $p<0.001$, b = $p<0.01$, c = p,0.05

* = Maximum monthly increase from mean during non-epizootic years.

** = Maximum monthly increase from mean during non-epizootic years.

Rainfall

Usually 9% of annual rainfall is recorded in August but it rose to 15% and 23% in 1985 and 1986, respectively. The total August rainfall was 166% of the 11 year mean in 1985 and 256% in 1986. At Roches' Point, 20% of the annual rainfall occurs during the summer (June to August), but this rose to 30% during 1985 and 37%during 1986. The normal summer/autumn rainfall ratio of 1:1.4 was reversed, with values of 1:0.8 and 1:0.4 being recorded in 1985 and 1986, respectively.

Rain/windchill factor

Figure 4 shows the mean monthly rain/windchill factor for 1979-1989, together with the 1985 and 1986 values. Significant increases coincided in April and August of both years, while a significant rain/windchill factor decrease was detected in October 1985 and 1986.

Statistical Significance

Table 2 shows the significant differences from mean monthly values which occurred in each year from 1979-1989. Significant deviations from the mean occurred frequently showing the inherent variability of meteorological features and the difficulties of associating such variability with disease outbreaks. Undue emphasis would have been placed on the 1985 and 1986 results had t-tests not been performed on the mean monthly values for each year of the 11 year series. Nevertheless, it can be seen that 1985 and 1986 had more months with temperatures significantly below the mean, (5 and 6 compared to 2.8) and had more months which were very ($P<0.001$) and higher $P<0.01$) significantly colder, windier and with higher rain/windchill factors than the mean.

Weather in County Cork

The biggest national monthly deviation from August mean temperature occurred at Roches' Point in 1985 while the largest national rainfall increase in the same month was recorded here in 1986. Thus, although the weather was inclement throughout the whole country, temperatures were lower and rainfall was higher in County Cork. The occurrence of 3 months in both years with very significant increases in the rain/windchill factor suggests that the weather directly influenced the occurrence of BHM outbreaks through increased cold stress of cattle.

Cold stress of cattle

Although cattle are normally tolerant of cold, dry heifers and cows have a higher critical temperature (*i.e.* temperature below which metabolism must be increased if body temperature is to be maintained) than lactating animals. In addition, the bovine udder is subjected to cold stress much more than the rest of the body and the rain/windchill values recorded in August 1985 and 1986 were as high as those usually detected between December and March when the winter hair coat has grown and cows are stabled for much or all of the time. The peak occurrence of BHM cases in October, one to two months after the cold, windy and wet conditions of August, cannot be explained simply in terms of the incubation period of experimental BHM, which is 2 to 9 days. However

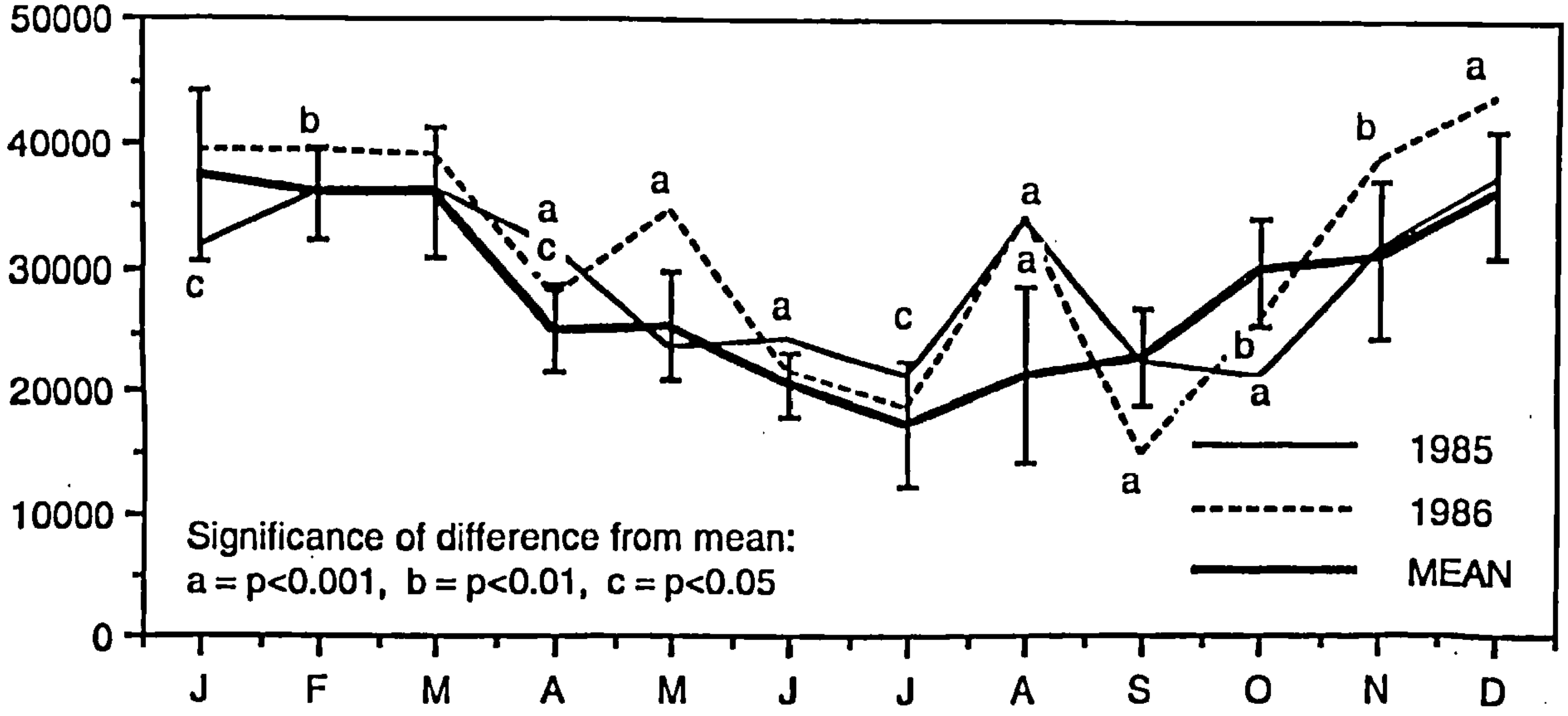


Figure 4. Mean monthly rain/windchill factor during 1979 - 1989 and during 1985 and 1986.

Table 2. Number of months with statistically significant deviation from mean temperature, windspeed, rainfall and rain/windchill factor during 1979 - 1989 and during 1985 - 1986.

	1979 - 1989						1985						1986					
	Average number of months above mean			Average number of months below mean			Months above mean			Months below mean			Months above mean			Months below mean		
	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c
Temp	0.8	1.0	1.6	1.0	1.0	0.8	-	-	3.0	2.0	2.0	1.0	-	-	-	4.0	-	2.0
WS	0.8	0.8	1.2	1.0	1.2	0.9	2.0	1.0	-	1.0	1.0	-	2.0	1.0	2.0	1.0	-	-
RF.	1.2	1.3	0.2	0.4	1.3	1.7	-	1.0	1.0	-	1.0	1.0	1.0	3.0	-	2.0	1.0	-
RW	1.0	1.2	0.8	1.4	0.6	0.5	3.0	-	1.0	1.0	-	1.0	3.0	2.0	1.0	1.0	1.0	-

Temp = Temperature, WS = Windspeed, RF = Rainfall, RW = Rain/windchill factor.

Significance of difference from mean: a = $p<0.001$, b = $p<0.01$, c = $p<0.05$

maximal correlation has been found in Northern Ireland between the occurrence of sheep pneumonia at slaughter and the rain/windchill values recorded 2 months and 1 month earlier. It is thus possible that the effects of cold, wind and rain are cumulative and additive. Indeed the cold stress may have been accentuated by the frost and fog which occurred during September and October.

Grass Growth

Figure 5 shows that grass growth was significantly reduced during March and April of both 1985 and 1986. Reduced grass growth in the spring, coupled with the two very wet summers, may have led to enhanced clover growth, with resultant increase of non-steroid phyto-oestrogens.

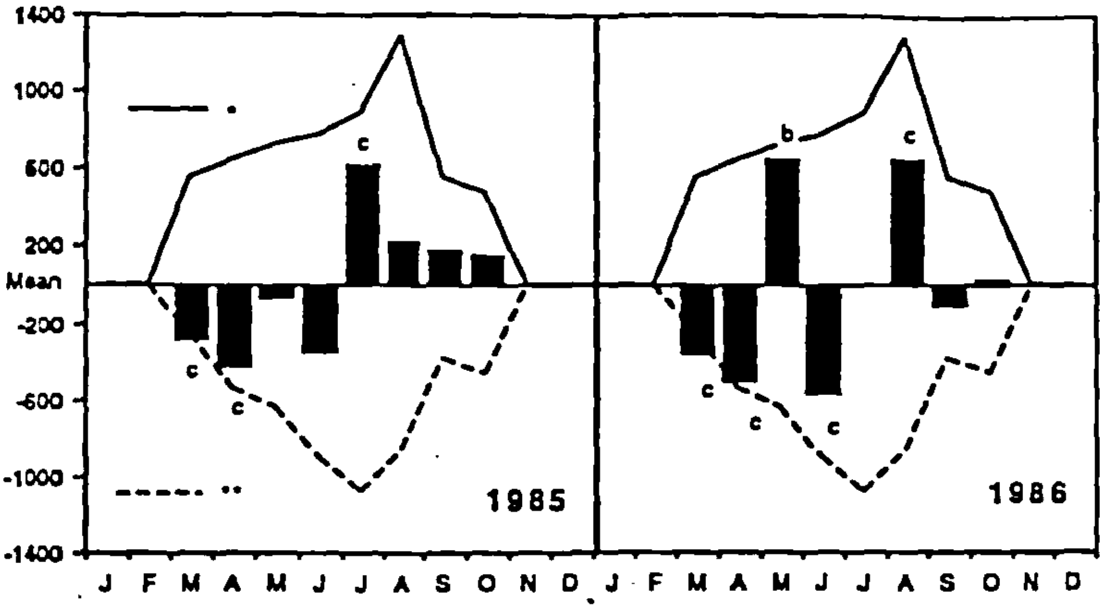


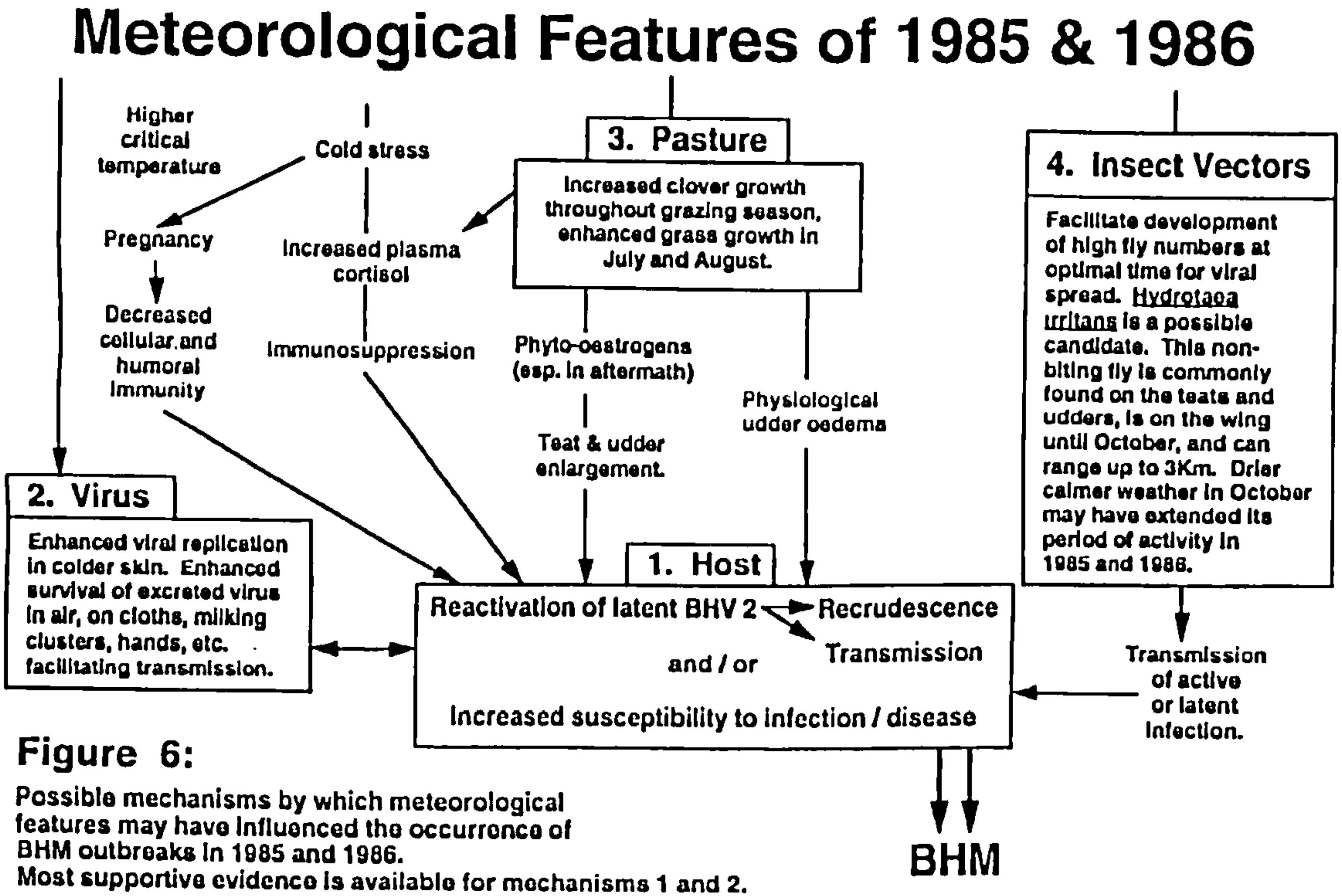
Figure 5. Deviation from mean monthly grass growyh during 1985 and 1986.

Significance of difference from mean: a = p<0.001, b = p<0.01, c = p<0.05

* = Maximum monthly increase from mean during non- epizootic years.

** = Maximum monthly decrease from mean during non- epizootic years.

Possible mechanisms for the direct and indirect influence of weather conditions on the occurrence of BHM are shown in Figure 6.



Meteorological Features of 1985 & 1986

Higher critical temperature

Cold stress

Pregnancy

Decreased cellular and humoral immunity

Increased plasma cortisol

Immunosuppression

3. Pasture

Increased clover growth throughout grazing season, enhanced grass growth in July and August.

Phyto-oestrogens (esp. in aftermath)

Teat & udder enlargement.

Physiological udder oedema

4. Insect Vectors

Facilitate development of high fly numbers at optimal time for viral spread. *Hydrotaea irritans* is a possible candidate. This non-biting fly is commonly found on the teats and udders, is on the wing until October, and can range up to 3Km. Drier calmer weather in October may have extended its period of activity in 1985 and 1986.

2. Virus

Enhanced viral replication in colder skin. Enhanced survival of excreted virus in air, on cloths, milking clusters, hands, etc. facilitating transmission.

1. Host

Reactivation of latent BHV 2 → Recrudescence

Transmission

and / or

Increased susceptibility to infection / disease

Transmission of active or latent infection.

BHM

Figure 6:

Possible mechanisms by which meteorological features may have influenced the occurrence of BHM outbreaks in 1985 and 1986.
Most supportive evidence is available for mechanisms 1 and 2.

Disease Prediction

The possibility of using meteorological data for prediction of BHM occurrence is presented by examining the weather of 1988. No cases of BHM were reported to the laboratory in that year, the meteorological features of which were very close to those encountered in 1985 and 1986. June, July and August were colder, July was windier, and July and August were wetter than the mean. However, the weather differed from 1985 and 1986 in that August was not windier than the mean and did not record a high rain windchill value, while October had both a high rainfall and a high rain windchill value. Grass growth in 1988 was significantly above the monthly mean from March to September. These results provide further evidence that the meteorological and grass growth features common to 1985 and 1986 were associated with the occurrence of outbreaks of BHM.

Disease Prevention

The most useful preventive measure appears to be the provision, to pregnant heifers, of shelter from wind and rain, at least from the beginning of August, perhaps supplemented by feeding with hay. It may also be helpful to keep such animals from grazing aftermath, especially if it contains much clover.

CONCLUSION

Extensive outbreaks of BHM occurred in Co. Cork in 1985 and 1986.

Many months in these years were colder and windier than the mean. Excessive rainfall was recorded in August, resulting in reversal of the usual summer/autumn rainfall ratio. The rain/windchill factor during August was as high as that usually detected during December to March. October was drier than the mean.

The weather most probably contributed to the occurrence of BHM outbreaks by causing cold stress of cattle, and by facilitating prolonged survival of excreted virus. Udder enlargement and oedema may have been accentuated by increased phyto-oestrogens in clover and by lush autumn grass. Meteorological conditions may have facilitated mechanical transmission of BHV 2 by insect vectors.

The results suggest that meteorological data may be used to predict outbreaks, and that simple preventive measures may be effective.

Acknowledgements

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