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Dublin, February 29, 1988

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Preface

Understanding the significance of weather to agricultural production is an important pre-condition for improving farming efficiency. Performance cannot simply be measured in terms of the yield harvested but by the quality of the produce and the efficiency of production. It is now realised that the industry is not only dependent on its climatic environment but also especially sensitive to it.

During the annual agricultural cycle food producers are concerned with soil workability, growing conditions and disease control, harvesting, and conditions related to storage and transport. The influence of weather on production is both direct and indirect: it directly determines growing conditions through levels of solar radiation and temperature, and the availability of moisture; it has an indirect influence on other production factors such as quality and disease. The effects of agricultural activity on the ecological environment also demand producers' attention. Ideally decisions should be made more objective by the use of appropriate agroclimatic information and the inclusion of short and medium term weather forecasts.

Computer modelling of crop growth and disease progress is an important means of increasing our knowledge about the state of crops in a weather dependent environment. In addition appropriate information systems can provide for improved production by better timing of management action, decreased losses from adverse weather and disease, and reduced costs through more efficient use of resources. Close links between meteorologists and agricultural advisers are important in this respect.

The AGMET Group was formed on February 29, 1984 and to mark the anniversary occasion a Conference on Weather and Agriculture was held on *AGMET-day*, February 29, 1988 at University College, Dublin. The Conference had as its theme **the interpretation and application of weather to agriculture.** Nine papers were presented reflecting the current state of the art in western Europe and in Ireland. In keeping with the interdisciplinary composition of AGMET a range of topics was covered including a keynote paper on the role of meteorology in agriculture by Dr. R.A. Feddes, Institute for Land and Water Management Research, Wageningen.

The large attendance also learned from Dr. D.J. Royle, Long Ashton Research Station, Bristol, of the progress made towards developing reliable plant disease forecasts in Britain. The place of modelling in relation to soils and crop growth, and to major crop and animal diseases, was discussed. Topics such as features of the Irish climate and aspects of the environment of importance to agriculture, efficient pasture management, and trends in weather forecasting, completed the wide range of papers from a number of Irish agricultural and meteorological scientists.

As part of the Conference a scientific exhibition was mounted which showed important facets of the effects of weather and climate on agriculture. The exhibition included: the display of automatic weather recording both by promotional companies and operational services; crop and evaporation computer models; the Foot and Mouth Disease dispersal programme; the Agriline videotex service; poster displays on the effects of weather on forestry; and the influence of climate on crop diseases.

The Conference could not have been held without the generous support of the sponsoring companies and the parent institutions of the members of AGMET. We are indebted to the School of Architecture, Faculty of Agriculture and Computer Services, UCD, for providing Conference and support facilities. Local organisation by Dr Jim Collins and his colleagues was invaluable to the success of the Conference. Grateful thanks is also expressed to the chairmen for the sessions, Professor Jack Grainger, TCD, Dr. Paddy Barry, UCD and Mr.Donal MacCarthy AFT, Moorpark Research Centre. Help with the publication of the Proceedings by the Meteorological Service is also gratefully acknowledged.

It is hoped that the discussion begun on *AGMET-day* will go beyond the confines of the Conference room and prove a stimulus for further advances in agricultural meteorology in Ireland.

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ROLE OF METEOROLOGY IN AGRICULTURE

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Abstract

Nowadays diagnostic computer models have been developed that are able to describe the influence of weather as a day-to-day variable on crop growth, yield and on farming operations. For operational application these models have to be used in a prognostic way and have to be fed with meteorological data that are obtained from automatic weather stations. Examples of model use are presented for a number of agricultural applications.

Introduction

Effects of meteorology upon agriculture can be distinguished in two ways. Firstly the climate determines for a specific region which type of crop can be grown and what will be the maximum possible yield a farmer can obtain, provided there is an optimal supply of water and nutrients. Secondly the daily weather determines if timely farming operations are possible.

During the season farmers keep a much closer eye on weather forecasts than the remainder of the population. Reliable forecasts make it easier for them to plan their field work. According to Hrbek (1983) farmer's decision-making can be classified in three categories (Fig. 1).

These may be of an:

- *operational character:* short-term decisions covering a few hours up to a few days. Short- and medium-termed forecasts or warnings are needed.
- *tactical character:* long term decisions covering a period of several weeks up to a growing season.Accordingly long term forecasts are needed.
- *strategic character:* decisions covering a period of many years. Hence statistical forecasts covering a series of years are required.

A problem with meteorological forecasts is that meteorologists are usually thinking in terms of macro-scale while the farmer is interested mainly in the forecast for his local plot. Therefore there is nowadays a tendency of providing in addition to the general weather forecast more detailed micro-meteorological forecasts on a regional scale. Meteorological consultancy and public services anticipate this need by providing daily advice on expected meteorological conditions directly to the farmer by telephone. Such services presume that a professional farmer is able to draw the necessary conclusions, i.e. that he is able to convert the meteorological information into relevant decisions on his farming operations.

Since the last few decades a number of computer models have been developed that describe the influence of weather as a day-to-day variable on processes such as plant and animal deseases, performance of farming operations such as trafficability and workability, evapotranspiration, soil and moisture balance, seedling emergence, crop growth and production, pests, drying of hay, drying of grain, etc. The outcome of such models may be of help to the farmer to evaluate his decisions and to understand the sensitivity of the system to variation in weather conditions. Models also can be of use in evaluating hypothetical situations that might occur in the future.

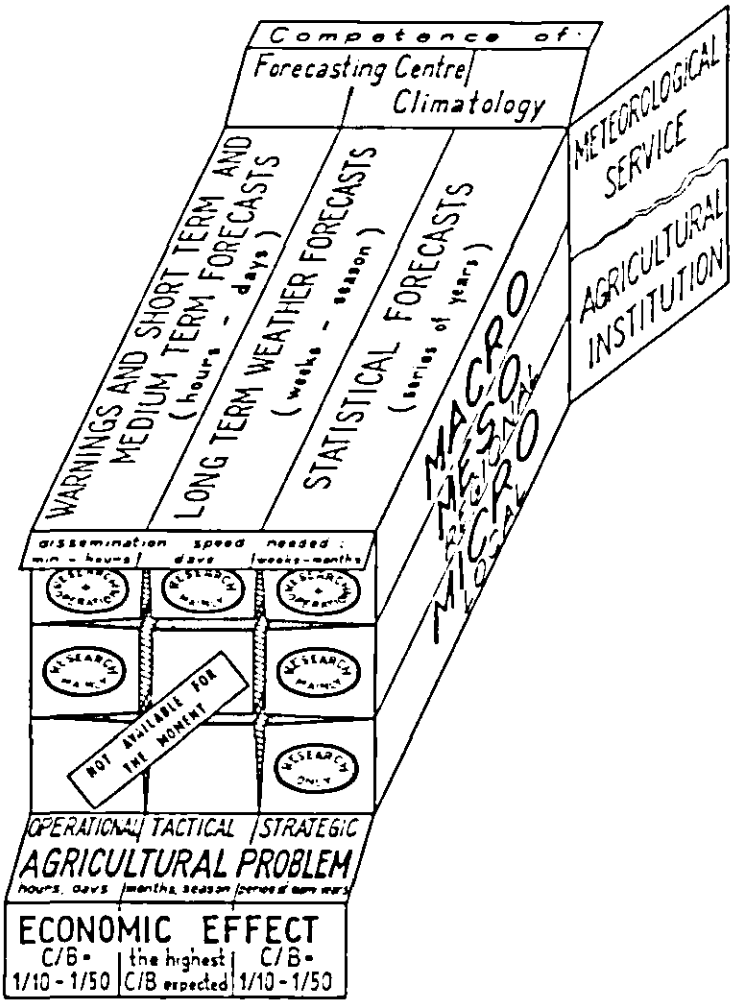

Fig.1. General classification of agrometeorological surveying according to the character of the agronomic problem, the dimension of the area covered, and the responsibility within and outside National Meteorological Centre (after Hrbek, 1983)

The models discussed so far are of diagnostic nature: they analyze in detail the influence of the meteorological conditions on the physical processes involved. If such models are going to be used operationally in crop and farm management systems, the meteorological input data in these models should be of prognostic nature. Hence the existing diagnostic models have to be transformed into prognostic models in close cooperation with meteorologists and agriculturalists. Only in this way optimal use can be made of existing data bases and software modules. The crop/farm management systems are really able to analyze, to plan and to aid in decision making for the farmer.

In the following the role of meteorology in agricultural production systems will be illustrated with a number of examples of application. The model approach as followed by the present author in evaluating under the prevailing meteorological conditions effects of water management on farming operations and crop growth/yield will be dealt with in more detail. Finally means of improving farm management and possibilities of controlling agricultural operations in future will be discussed. Part of the material presented here has been subject of discussion in the Dutch task-group on Agrometeorology of the National Council for Agricultural Research (NRLO).

In the following a number of areas are listed in which meteorological information has or can play a major role. Needs for further meteorological/agricultural research are emphasized.

Air pollution

Effects of air pollution on plants are determined by the concentration and the residence time of phytotoxic components inside the cells of the plant. The process of uptake, (possible) conversion and further transport of these components is influenced by the concentration of the toxic component in the air and the way and duration of exposition. Important meteorological parameters that may characterize the conditions of exposition are notably: air temperature, air relative humidity, wind speed, leaf wetness period and light intensity.

Plant diseases

Most plants suffer from diseases which depend on the weather. Weather data can be converted into indices of disease risk. These indices are used by plant pathologists in combination with information on crop growth stages and disease levels currently present, resulting in recommendations on whether spraying is ncessary and on the optimum timing of sprays. An important meteorological parameter in this context is leaf-wetness, which determines the formation of fungi. For example wheat is often affected by fungal diseases such as rust, mildew and septoria.

EPIPRE (e.g. Reinink, 1986) is an operational computer model that is presently used in the Netherlands to advise the farmers about spraying against diseases and plant-losses in winter wheat. In his model exact determination of the various phenological development stages is necessary. Especially during the flowering and ripening phase farmers have difficulties with the determination of the proper phenological stage. One now lets the model predict the stages based on sowing date, temperature sums and daylengths. Input of actual meteorological data being collected on a regional basis are required to predict both the phenological stages and the speed of extension of the diseases and plant-losses properly, and when spraying is most effective. EPIPRE provides the user also with a cost-benefit analysis of possible sprayings.

Schreuder (1985) found from a regional weather forecasting experiment in the IJssel-lake polders of the Netherlands that arable farmers considered spraying as one of the most important activities. As a consequence they were mostly interested in forecasts of rainfall and wind.

Animal disease

The development of animal parasites and nemathodes also depend on the leaf-wetness of grass. Larvae can move upward only if the surroundings are sufficiently wet. It is not yet known how many dry days are necessary to prevent upward migration. A problem is that measurement of leaf-wetness is still complicated and apparently measurements are not accurate enough.

Weeds

Seeds of weeds can remain for a long time in the soil without germination. Only when the conditions of soil moisture and temperature are optimal, weeds start to emerge and to grow. With information about the variation of soil moisture and temperature with time one may predict the development of weeds. Hence killing of weeds can be done more effectively, thus decreasing the costs.

Timeliness of Farming Operations

In North-Western Europe farming operations are usually largely affected by the weather conditions. If for example the soil is too wet because of (too) much rain timely soil farming operations are not possible. Because the strength of the soil depends largely on the soil moisture content, wet conditions result in a decrease in accessibility, trafficability and workability of the soil. Moreover, performing farming operations under too wet conditions results in soil compaction and more soil degradation. In addition operations have to be performed in a short time, thus affecting the requirements for labour and machinery capacity.

Crop farming operations such as grain harvesting or haymaking are also strongly related to the weather conditions. The moisture content of the grain and straw determines if harvesting by combines is possible. In addition it determines what will be the amount of grain losses during harvesting, the quality of the product obtained and the costs for drying in grain silos afterwards. If a relationship can be derived between the grain, and also straw moisture content, and some meteorological variables, the variation of moisture content with time can be reconstructed and then be predicted from short term weather forecasts. For cut grass the process of drying depends on the meteorological conditions, the properties and layering of the grass swath and the moisture condition of the underlying soil. A drying expectation based on weather forecasts can help the farmer a lot in taking the right decisions. Schreuder (1985) stated that as a criterion for drying of mowed grass a 'reference evaporation sum' of 8-10 mm is required to reach the necessary dry matter content of 40 to 50 per cent. According to Ansaletho *et al.* (1985) farmers in Finland considered agrometeorological services with respect to haymaking and grain harvesting as the most beneficial to them.

There are generally two ways to determine from short term weather forecasts the planning and the amount of workable time for soil and crop operations. The first is to transform the forecast into meteorological data and use these prognostic data as actual input data in the simulation models. The second is to run the models for many years and to derive for various classes of forecasts and moisture content of the soil/crop the average number of workable hours (e.g. Eleren, Van, 1977; 1987).

Fertilization

To advise farmers about the optimum time and amount of fertilization, meteorological data are indispensable. Also for the calculation of soil nitrogen mineralization and denitrification, percolation losses and the nitrogen demand of the crop, these data are necessary. The more so because farmers generally apply too much fertilizers, with the danger of polluting the groundwater. Another problem is the emittance of ammonium (NH_3) from manure that is spread over the field to the atmosphere. Emittance occurs either from the liquid or the gas phase. The first is usually described by transfer coefficients that are calculated from wind velocity and air temperature data measured at a certain height. Emmittance from the gas phase seems to be more complicated as the process is influenced by turbulence and absolute pressure differences in the atmosphere. With respect to the losses of NH_3 to the subsoil by convective water transport, the amount and distribution of rainfall as well as evaporation are important.

Evapotranspiration

From the previous examples of applications it is clear that estimation of potential evapo(transpi)ration is an important item. From meteorological data the potential evapo(transpi)ration of bare soils and cropped surfaces can be estimated, e.g. by means of the well-known Penman-Monteith (1965) - Rijtema (1965) equation:

$$\lambda E_p = \frac{s(Q^*-G) + \rho_a c_p (e_s - e) r_a}{s + \gamma(1 + r_s/r_a)} \quad (\mathrm{W.m^{-2}}) \tag{1}$$

where :

λ = latent heat of vaporization of water ($\mathrm{J.\ kg^{-1}}$)
E_p = potential evapotranspiration ($\mathrm{kg.m^{-2}.s^{-1}}$)
s = slope of the saturation water vapour pressure temperature curve at air temperature ($\mathrm{hPa.K^{-1}}$)
Q^* = net radiation flux density ($\mathrm{W.m^{-2}}$)
G = soil heat flux density ($\mathrm{W.m^{-2}}$)
ρ_a = density of the air ($\mathrm{kg.m^{-3}}$)
c_p = specific heat of air at constant pressure ($\mathrm{J.kg^{-1}.K^{-1}}$)
e_s = saturated vapour pressure at air temperature at screen height (hPa)
e = water vapour pressure at screen height (hPa)
r_a = diffusion resistance for water vapour transfer of the air layer betwen the ground surface and screen height ($\mathrm{s.m^{-1}}$)
γ = psychrometer constant ($\mathrm{hPa.K^{-1}}$)
r_s = canopy or surface resistance ($\mathrm{s.m^{-1}}$)

In eq.(1) the canopy resistance r_s needs to be known. A minimum value for this resistance seems to be 30 $\mathrm{s.m^{-1}}$ for arable crops and 150 $\mathrm{s.m^{-1}}$ for forests. For the most important agricultural crops the canopy resistance is determined experimentally by using the above mentioned equation, where evapotranspiration is measured independently by either a micrometeorological approach (e.g. Bowen ratio) or a soil water balance method. The Penman-Monteith-Rijtema equation is not able to describe the potential evapotranspiration of (row)-crops with sparse cover. To overcome the problem of the uncertainties in the value of the canopy resistance, one often applies the empirical so-called crop factor method. Herein is the evaporation of a hypothetical shallow water surface ("open water evaporation") E_o as calculated by the Penman (1948) equation multiplied by a suitable crop factor g to obtain potential evapotranspiration E_p.

$$E_p = g\, E_o \tag{2}$$

where E_p is obtained from soil water balance measurements with sprinkling experiments from fields with different local conditions and agricultural practices. These local effects may include size of fields, advection, weather variations in time, irrigation and cultivation practices, soil water availability, etc. Because of the large number of meteorological input data that are required in the Penman equation (net radiation!) in the Netherlands another approach has recently been adopted (see De Bruin, 1987; Feddes, 1987):

$$E_p = f\, E_r \tag{3}$$

where f is a new crop factor and E_r is the potential evapotranspiration of grass according to Makkink (1957), expressed as:

$$\lambda E_r = 0.65 \frac{s}{s+\gamma} K\downarrow (W.m^{-2}) \qquad (4)$$

where $K\downarrow$ is global radiation ($W.m^{-2}$). The advantage of eq.(4) is that as input global radiation and temperature (through the terms $s/(s + \gamma)$) only are needed, which are measured directly in the Netherlands on a sufficient number of routine stations.

In crop growth simulation models a distinction has to be made between (potential) transpiration and soil evaporation. This is because transpiration and photosynthesis are directly related through the opening of the stomata of the leaves. Some semi-empirical approaches however have been developed (e.g. Feddes, 1987).

Still a lot of problems with respect to the estimation/measurement of evapotranspiration need to be solved such as: spatial variation; temporal variation; connection between local evaporation and large scale evaporation; influence of advection with small fields, row-crops and solitary trees; leaf-wetness period, dew; separation of transpiration and soil evaporation; specific plant/crop behaviour; evaporation of soil under various conditions of tillage; influence of windshields upon evaporation (and crop production), etc.

Soil Moisture

In order for the crop to meet under the prevailing meteorological conditions the potential evapotranspiration demand (and thus optimal growth!) the soil moisture status of the soil must be optimal. The soil water balance accounts for the incoming and outgoing fluxes of a soil compartment, i.e. the root zone:

$$\Delta M_r = I + Q_r - E \ (mm) \qquad (5)$$

where M_r is the change in moisture storage, I is infiltration (including irrigation), Q_r is net upward flow through the bottom of the root zone and E is evapotranspiration. The problem with eq.(5) is that is is very difficult to evaluate Q_r properly. This flow is the resultant of capillary rise and percolation. Often one does not consider capillary rise from deeper soil layers and/or the groundwater table: what has been percolated through the root zone is simply lost. In the presence of a groundwater table eq.(5) cannot be applied. Then one should take into account in detail the water transport below the root zone.

Feddes *et al.* (1978) have developed the computer model SWATR (Soil Water Actual Transpiration Rate) to describe transient water flow in a heterogeneous soil-root system, which is under influence of groundwater. A new version SWATRE (exended) was developed by Belmans *et al.* (1983) who applied a different numerical solution scheme and extended the possibilities of using different types of boundary conditions at the bottom of the soil system. Input into SWATRE consists of: initial pressure head distribution with depth, 24-hour data on rainfall, potential soil evaporation and potential transpiration, the soil water characteristics and hydraulic conductivity curves for the different soil layers, rooting depth (varying with time), critical pressure head values for water uptake by roots and drain depth and - intensity. The output of the model consists of all terms of the water balance, the distribution of moisture contents/pressure heads/fluxes over depth and time, including the water uptake by the roots. One of the main outputs is actual tanspiration, calculated as the integral of the sink term over the rooting depth. The model is operational and has been used for a number of applications such as for irrigation scheduling in farm management systems (Wesseling and Van Den Broek, 1987), evaluation of effects of drainage, soil improvement etc.

Simulation of different irrigation regimes by models such as SWATRE enables one to find the optimum regime. Different desiccation limits were allowed for potatoes grown on a humous top soil overlying coarse sand after which irrigation was applied. Simulations were performed for the 1981 and 1982 growing season in the Netherlands with the natural rainfall being 209 and 182 mm respectively. Actual transpiration was computed and the irrigation efficiency was plotted versus the net irrigation amount. The result is presented in Fig. 2. It appears that in 1981 the water use efficiency varied from 0.51 to 0.73 and in 1982 from 0.67 to 0.87. The efficiency curve is apparently non-linear and depends for a certain crop and soil on amount and time of water application and natural rainfall conditions (both amount and distribution in time). In problems of irrigation management these types of curves have to be known in irrigation optimization studies.

Dryness may have adverse effects on plant growth. Next to a decrease in total dry matter production unwanted changes of vegetative to generative phase and reallocation of biomass inside the plant may occur. Irrigation at proper times and correct amounts will then have a favourable effect.

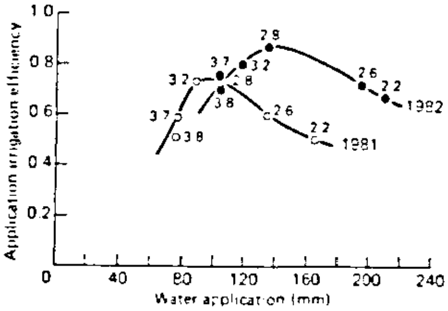

Fig.2. Irrigation efficiency (defined as the ratio of the difference in transpiration T between the sprinkled and the not - sprinkled field over the amount of water applied) versus the net water application, for a potato crop growing on a humous top soil overlying a coarse sand, for the 1981 and 1982 growing season. The desiccation limits that were used are expressed in pF- values (= log |h|) and are indicated along the curves.

Crop production

De Wit (1965) has developed a method to calculate for every time and place on earth for which the meteorological data are known, the daily maximum possible photosynthesis rate of a closed canopy that is well supplied with water and nutrients and does not suffer from diseases, weeds. In it's present day form the equation reads as:

$$q_m = [P_{st} \; (1 - e^{-\nu I}) - \chi_m]c \quad (kg.ha^{-1} \, .d^{-1}) \qquad (6)$$

where P_{st} is the photosynthetic rate ($kg.ha^{-1}$ $.d^{-1}$) of a so-called "standard canopy" defined as having a leaf area index of 5 (ha leaves per ha soil surface), ν is solar radiation extinction factor ($\nu = 0.75$), I is leaf area index ($ha.ha^{-1}$) of the actual crop under consideration, χ_m is maintenance respiration (CH_2O in kg.ha $^{-1}$ .d $^{-1}$) and c is a factor (c = 0.8) to convert sugars into starch. The advantage of eq.(6) is that one can test if for a certain crop growing in a certain area conditions are really optimal.

To evaluate effects of water management upon crop production one would like to have a soil water - crop growth model that is as simple as possible, having parameters few enough to be all measured directly or indirectly, and where the crop and soil system have a clear interaction with each other. Crop development with time should not be a-priori information, but there should be a feedback with calculated actual transpiration/production rated. the rate of dry matter growth of a crop having an optimal supply of nutrients can be calculated by the model CROPR(CROp PRoduction) of Feddes *et al.* (1978), in which the growth rate depends on transpiration rate according to a nonrectangular hypebola (Fig.3). Feddes *et al.* (1984) combined the SWATRE and the CROPR model into one model SWACRO, which generates a simulation of the actual development of a (potato) crop.

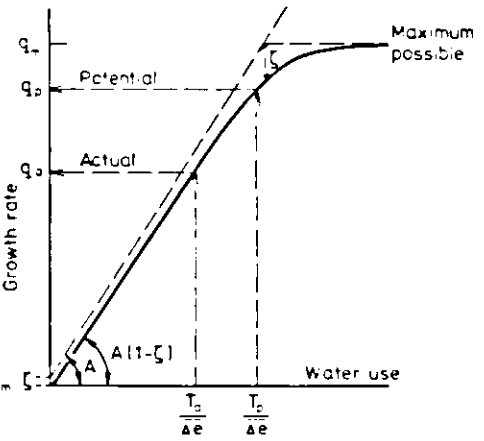

Fig.3. Growth rate versus water use described as a non- rectanglar hyperbola, bounded by two asymptotes. The left asymptote indicates the productivity of a crop for water that is well supplied with nutrients. The upper horizontal asymptote represents the production level under conditions of adequate supply of water and limited supply of some other growth factor that represents weather conditions, in particular solar radiation (after Feddes *et al.*, 1978).

A special feature of crop production that has come up recently is the growth of short rotation forests, that are important for use as sources of energy and for use as raw material by forest industry. For example in Sweden willows are grown for this purpose and efforts are being made to examine how environmental factors are affecting growth as well as to develop selection criteria for use under a wide variety of climatic regimes, land types and cultivation intensities (e.g. Nilsson, 1985). This type of alternative land use is attractive as compared with burning peat for example.

In the foregoing a number of applications of meteorology to agriculture have been mentioned, that illustrate the importance of weather influence on every day agriculture. In the following an example is given of an integrated model approach that considers the day-to-day weather influence on crop yield for various conditions of drainage.

Simulation Effects of Soil Type and Drainage on Arable Crop Yield

Van Wijk and Feddes (1986) developed on the basis of the non-stationary FLOWEX and SWATRE model an integrated approach that predicts effects of changes in water management by drainage on trafficability and workability in spring, sowing/planting time, emergence date, transpiration, growth and dry matter yield of potatoes and summer wheat. A flow chart of the integrated model approach is presented in Fig. 4.

Input to FLOWEX includes 24-hour rainfall and potential soil evaporation, soil water retention and hydraulic conductivity curves of the different soil layers, drain depth and -intensity, and initial soil water content distribution. One of the outputs is the soil water pressure head at 5 cm depth, which determines the time and number of days that the soil is workable. By knowing the critical pressure heads and the number of days required for seeding/planting one predicts the time when these operations are finished. Then the emergence date is predicted on the basis of the heat sum required for emergence under optimal/non-optimal moisture conditions. SWARTE, which starts running at the emergence date, requires in addition to the input of FLOWEX potential transpiration, rooting depth (varying with time) and critical pressure head values for water uptake by roots. One of the outputs is the potential and actual crop transpiration.

Input for the hyperbolic crop production model CROPR (Feddes *et al.*, 1978; Feddes, 1986) includes actual and potential transpiration, maximum water use efficiency, determined from field experiments, shortwave solar radiation, air temperature, relative humidity, windspeed, leaf area index and some crop constants. (The crop is supposed to be optimally supplied with nutrients). Output of CROPR includes the maximal and actual daily total dry matter growth rate.

The increase in total dry matter production is then distributed over above and below ground material as a function of crop development stage. Total dry matter of leaves and below ground material can then be obtained. From the former the new leaf area index for the next day is determined. Day by day growth rates are summed up to obtain finally maximum actual dry matter yields. In autumn the suitability for harvesting root crops is determined similarly to the approach followed in spring: the pressure heads at 10 cm depth for sugar beet and at 15 cm depth for potatoes are computed by FLOWEX. Taking into account the critical pressure head limits, the time and number of workable days are obtained.

To evaluate the influence of harvesting conditions on crop yield the SWATRE-CROPR model calculates the yield until the last possible date, for example, 1 December for sugar beet because of frost risk. On the basis of the computed pressure heads in the top layer the time and number of last possible harvesting days are determined retrospectively and the yield computed at these days is taken as the final yield.

Van Wijk and Feddes (1986) evaluated with the integrated approach of Fig. 4 potato yields that were obtained for 30 years on a sandy loam soil at 5 different drain depths. They expressed separately the drainage effects occurring in spring and summer according to the relationship (for explanation, see Fig. 5):

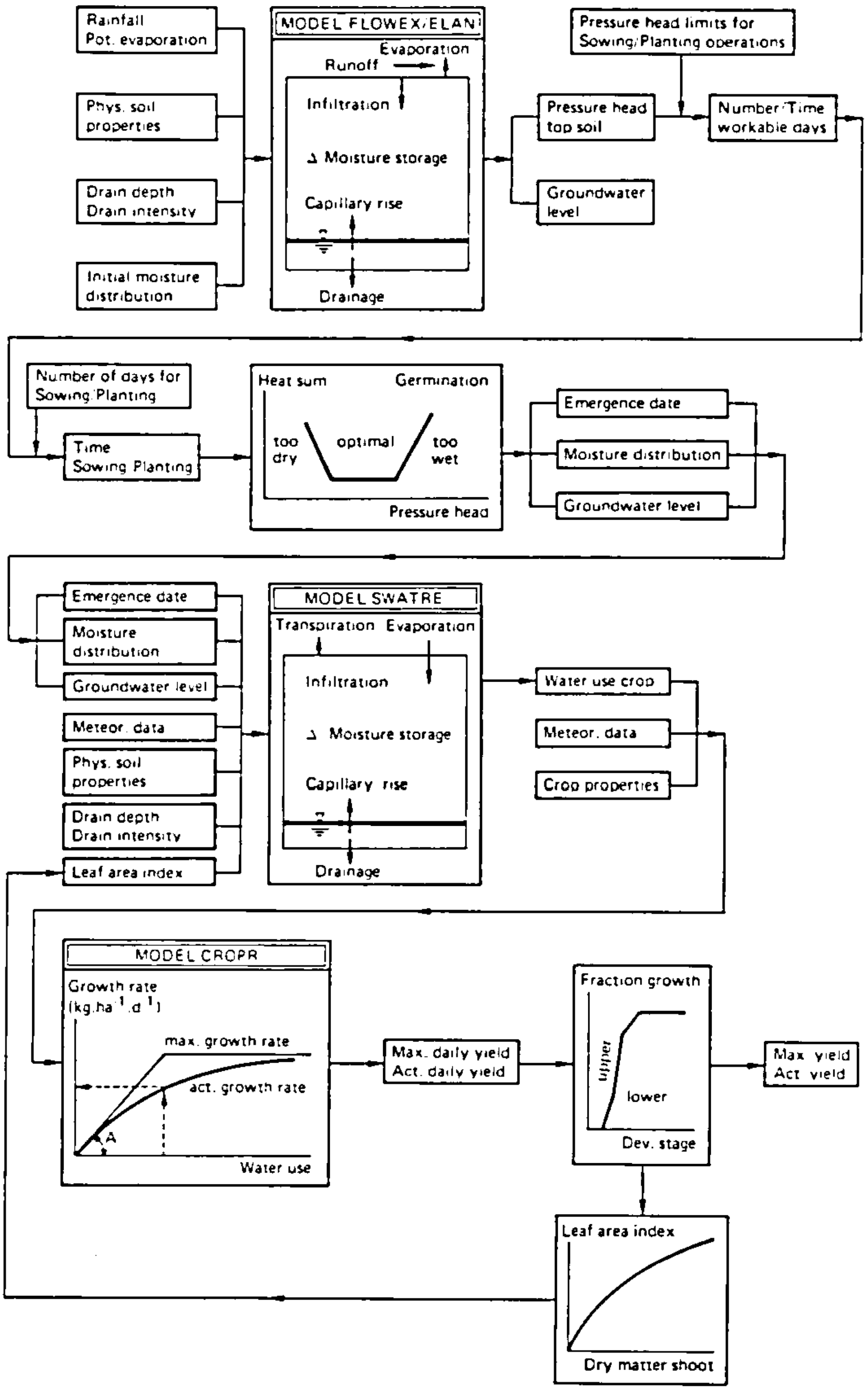

Fig.4. Flow chart of the integrated model approach for computing the influence of water management on yields of arable land (after Van Wijk and Feddes,1986)

$$\frac{Q_{act}}{Q_{max}} = \frac{Q_{pot}}{Q_{max}} \cdot \frac{Q_{act}}{Q_{pot}} \qquad (7)$$

The spring term accounts for the reduction in dry matter yield Q as a result of retardation in the planting and emergence date due to wet soil conditions in spring. The growing season term quantifies the shortage of water occurring during the growing period. Total drainage effect Q_{act}/Q_{max} is the product of spring and growing season effects. The value of Q_{max} varies with soil type because for example sandy soils can be planted earlier than clayey soils; hence eq.(7) can be extended to take this effect into account.

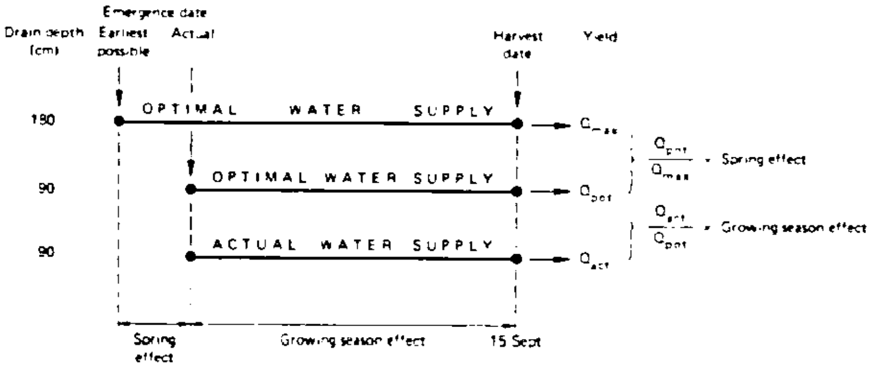

Fig.5. Scheme to illustrate for a certain soil type the effects of drainage during spring, growing season and the combination of the two. At the deepest drain depth (i.e. 180cm) the earliest possible emergence date occurs. At shallower drain depths (e.g. 90cm) emergence date is delayed. Average harvest date of potatoes in The Netherlands is 15 September.

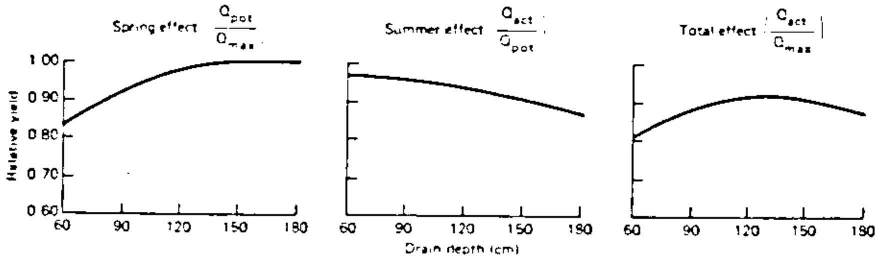

Fig.6. Relative yield of potatoes growing on a sandy loam versus drain depth. Drainage effects occurring in spring, summer and in the total season are presented as averaged over the 30-year period 1952 - 1981 (after Van Wijk and Feddes,1986)

In Fig. 6 the 30-years averaged relative yields due to drainage effects in spring, summer and over the total season are shown at 5 drain depths. On the sandy loam soil considered the spring effect is much more pronounced than the summer effect. Minimum drain depths of 150 cm are required to prevent yield reduction because of delayed emergence. Reduction of yield in summer is largest at 180 cm drain depth. The optimal drain depth that shows the highest relative yield over the total period is around 120 to 130 cm.

Conclusion

Agriculture in the EC is under large stress these days. There is over-production and there are environmental problems. With respect to the environmental pollution I would like to make the following remarks. Nitrogen fertilizer is quite cheap and is applied far too much these days. In grassland farming in the Netherlands nitrogen use can be reduced to let's say half, without affecting the yield too much. Another problem is the poor variety of arable crops we grow. In the Netherlands for many years we grow only potatoes, sugar beet and wheat. As a consequence half of the pesticide use in the Netherlands is necessary to grow potatoes each second year on the same soil.

In the future the price structure in the EC will change and the market will become a more regulatory instrument. A number of supporting measures will either change or completely disappear. Land will be taken out of agricultural production. The land that will remain will show a more intensive production system (with less people participating in it). More fertilizer and pesticides will be used per hectare but less per unit of product, thus causing less pollution.

Hence the structure of agriculture will change. The goal will not anymore be to obtain the last kilogram of dry matter production or the last extra litre of milk. The main aim will be to reduce the costs of farming. Crop and farm management systems can help a lot in taking the proper measures at the proper times, thus reducing the costs. In these management systems economical processes have to be included. Management decisions are thus to be taken based on model simulation, data bases, optimalisation techniques and expert systems. Short term weather forecasts and easily accessible meteorological data, preferably taken from regional, automatically operating weather stations are means that are indispensable to meet the goal of an optimally operating agriculture.

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FEATURES OF THE IRISH CLIMATE OF IMPORTANCE TO AGRICULTURE: COMPARISON WITH NEIGHBOURING EUROPE

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Abstract

Differences in the growing season as expressed by various parameters such as threshold temperature, degree days, frost-free season, are discussed with focus on Ireland and reference to northwest Europe. The mild Irish winter and cool summer lead to greater precipitation and less sunshine (radiation) compared with the neighbouring continent. The water balance (difference between precipitation and evaporation) has regional differences which lead to different farming practices. There is increasing difficulty in terms of successful field operations, e.g. tilling, silage making, hay saving, harvesting, towards the northwest. As the end of the grazing season is determined more by poor ground conditions than by the cessation of growth, the length of the grazing season in Ireland is estimated using an empirical formula based on annual precipitation and mean air temperature.

Introduction

The Oceanic Influence

Ireland, on the northwestern perimeter of Europe, has an oceanic climate. The mildness of the climate is to a large degree due to the warm waters of the North Atlantic Drift and a westerly airflow. The latter is often affected by cyclonic disturbances most of which pass to the northwest of Ireland and by quieter periods when the airstream becomes weakened and anticyclonic ridges develop. Because there are no great orographic barriers in northwestern Europe, the oceanic influence penetrates into the continent but is modified by latitude, distance from sea and relief (Wallen, 1970).

The Growing Season

Northwest Europe

The annual cycle of soil temperature follows a minimum in late winter, a recovery in spring, a maximum in late summer and a decline in autumn. Comparisons with growing seasons of the neighbouring continent (at inland stations) may be made using Table 1. At a threshold of 5.6°C (air temperature), which approximates the beginning of grass growth, the season ranges from 40 weeks in the south-midlands of Ireland, and in northern France to only 30 weeks in Denmark. At 10°C, the seasons are quite similar except in northwestern France and in Denmark whereas at 15°C Ireland is clearly the less favoured.

The rate of recovery of temperature in spring is also important for crop establishment or renewed spring growth. The rise over the three months mid-February to mid-May (Table 2) varies from 5.5°C in the south-midlands of Ireland to 12.0°C in northern Germany. As soil workability is both weather sensitive and weather dependent the timing of tilling operations is important. Higher initial temperature and a slower rate of recovery in Ireland suggest that farmers may have greater latitude to await suitable soil conditions in this country before undertaking spring tillage and planting operations compared with nearby continental areas.

Table 1 Duration of the Growing Season in Inland Northwest Europe

Threshold temperature	Ireland Kilkenny	England Cambridge	France Le Mans	Netherlands De Bilt	Germany Hannover	Denmark Strommen
			Weeks			
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

Table 2 Increase in Mean* Air Temperature, February to May

	Ireland Kilkenny	England Cambridge	France Le Mans	Netherlands De Bilt	Germany Hannover	Denmark Strommen
Mean Air temperature			°C			
February	5.3	3.9	4.6	2.8	0.6	-0.6
May	10.8	11.9	13.8	13.3	12.6	11.1
Increase (Feb-May)	5.5	8.0	9.2	10.5	12.0	11.7

*1931 - 1960

Focus on Ireland

Assuming 6°C (soil temperature) as the threshold for general grass growth (Connaughton, 1973), the regional variation in the median dates of the beginning of the season is shown in Figure 1(a). Southern regions and indeed western areas appear to be in a much more favourable position compared with the midlands and northeast.

The growing season or the potential of an area for the production of a given crop may also be expressed by means of degree-day sums. In their most simple form degree-days are an accumulation of mean (air) temperature exceeding a given threshold, the non-negative values for each day of (T mean- T thres) being added to the running total for a given season. T-sum 200, i.e. 200 degree-days(base 0°C)from January 1, has often been used in other countries, e.g. The Netherlands, as the best time to apply spring nitrogen (Jagtenberg, 1970). Figure 1(b) shows considerable regional variation in the averages of T- sum 200. While the T-sum 200 may not necessarily be the optimum application time in Ireland (note that although there is good agreement with Figure 1(a) in southern regions the dates drift apart considerably as we move to the northeast of Ireland), it is nevertheless interesting to examine the regional variations in the pattern of occurrence of T-sum 200. Slope, aspect, type of soil and the wetness of the land are important variables to be considered.

There are also important year-to-year variations in the length of the growing season as

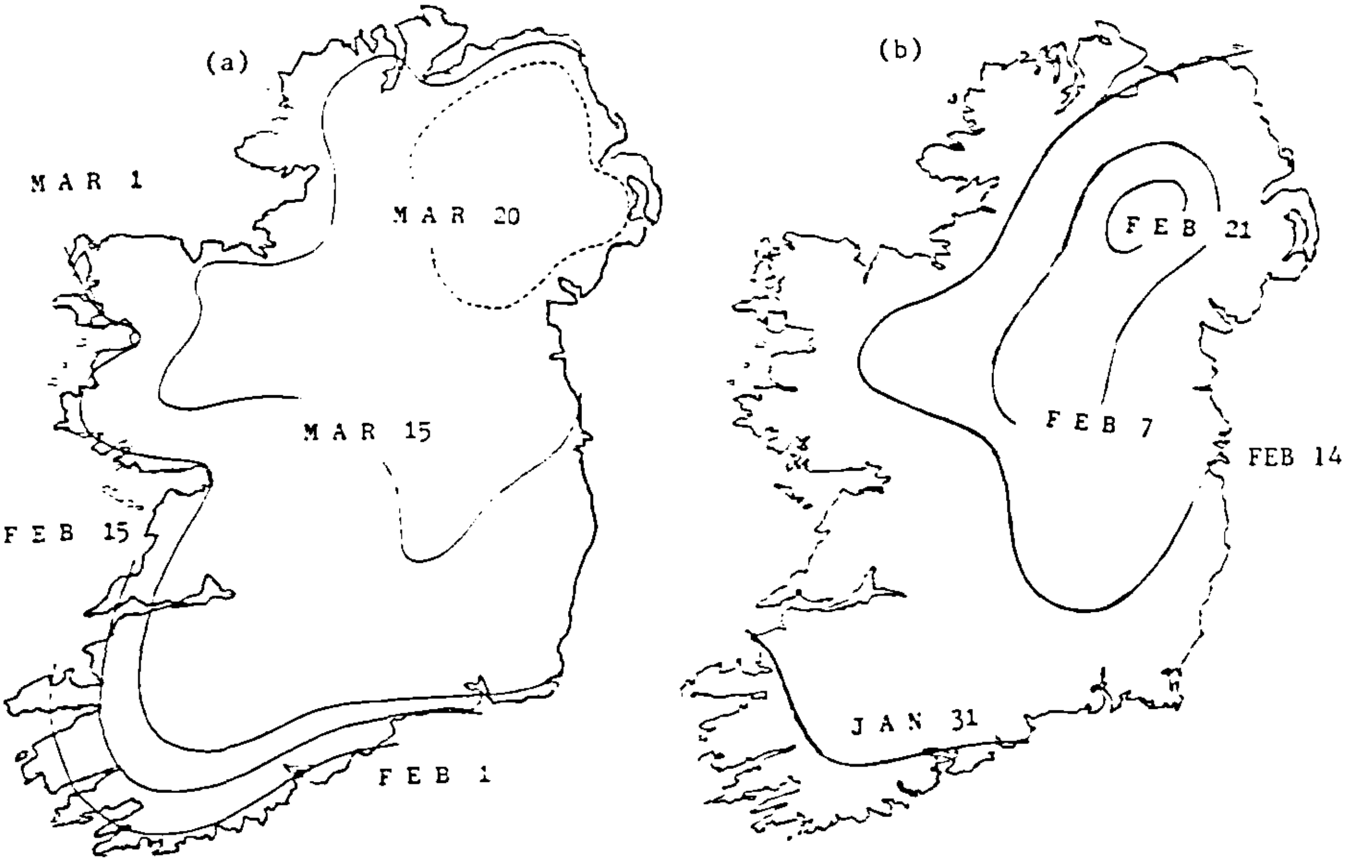

Fig.1. (a) Median date of beginning of grass growing season, 1954 - 1968 (after Connaughton 1973)
(b) Mean date of T-sum 200, 1960 - 1980

shown in Table 3. The season at Shannon Airport during the 1980's has varied from 226 days in 1984 to 294 days in 1981. While a succession of cold and warm spells is a normal feature of any year, the cold spells may not always be sufficiently intense for growth to cease. In some years however the season is shortened by a late cold spell in spring or lengthened by a late warm spell in the autumn. Connaughton (1973) states that the probability of the grass growing season continuing without check throughout the year in southern coastal areas is 33 per cent and that there is a 20 per cent chance the season would begin 14 days early in inland areas.

Table 3 Length of Grass Growing Season at Shannon Airport

Year	Start	Late Cold Spell (1)	Finish	Late Warm Spell (2)	Duration Days
1980	11/2	12/3 - 27/3	26/11		274
1981	21/1	08/2 - 04/3	05/12		294
1982	25/1	07/2 - 18/3	20/11		260
1983	1/3		08/12		283
1984	4/4		15/11		226
1985	29/3		10/11	11/12 - 21/12	238
1986	12/3		06/12		253
1987	26/2	09/3 - 22/3	23/11	15/12 - 31/12	272
Average	28/2		15/11		263

Incidences of Frost

Another method for expressing important limits to the growing season, especially for exposed or tender growing crops is by means of the frost-free season. While a spell of frost may well be desirable in winter to help improve the condition of ploughed land, the occurrence of air frost in late spring or early summer can have damaging effects on soft fruit or other horticultural crops with adverse consequences for production. Autumn frosts too can pose a threat to exposed harvested crops such as sugar beet or potatoes. The average dates of last air and ground frost in spring and first frosts in autumn, and the length of frost-free season at three representative stations are shown in Table 4. There are considerable differences in the frost-free season, both for air and ground frost, at the southern station at Roche's Point compared with both inland stations. Claremorris also is in a more favourable position vis-a-vis Kilkenny.

Table 4 Average Frost-free Season, Air and Ground, (1944 - '68)

	Alt.	Air Frost Last	Air Frost First	Frost-Free season (days)	Ground Frost Last	Ground Frost First	Frost-free season (days)
Roche's Point	43	24/2	06/1	316	13/5	22/10	159
Kilkenny	66	30/4	19/10	171	12/6	08/09	87
Claremorris	71	29/4	01/11	185	03/6	23/09	111

Growth Potential

Some comparisons of the growing potential from March to October based on degree-day accumulations exceeding 0°C, 5.6°C and 10°C air temperature at represenative stations are shown in Table 5. Using accumulations at Cahirciveen as standard, all other stations achieve lower totals except at Kilkenny which has the advantage at the highest base (10°C is more relevant for heat seeking crops). As the growth of crops also depends on radiation the differences in the growing potential shown in Table 5 must be modified in the light of regional differences in sunshine hours.

Table 5 Degree-day Totals March to October compared with Values at Cahirciveen

	0°C	%	5.6°C	%	10°C	%
Cahirciveen	2974	100	1634	100	735	100
Claremorris	2714	91	1426	87	640	87
Kilkenny	2825	95	1544	94	758	103
Clones	2708	91	1424	87	642	87

The Radiation Climate

The radiation climate of Ireland is most widely measured in terms of bright sunshine hours (at 84 stations) and more recently at a restricted number (8) of meteorological stations in terms of global radiation. Other radiation parameters such as diffuse and particularly net radiation are measured to a lesser degree. Annual bright sunshine totals vary from 1600 hours in the southeast to about 1100 hours in parts of the west and northwest (Fig. 2(a)). These amounts represent no more than 25 to 30 per cent of possible values. Ireland is not as well favoured compared with neighbouring regions of the continent - 1800 to 1900 hours sunshine in southern coastal areas of England, the Netherlands and in the north of France. There are also important seasonal variations due to regional influences (Keane, 1986). Sunshine hours in the southeast of Ireland increase from spring to summer by about 15 per cent but the opposite occurs in the northwest where a decrease of 5 per cent is noted (Fig. 2(b)).

Whereas May is normally the sunniest month of the year (although only marginally greater than June), the greatest inter-monthly increase in sunshine hours occurs between March and April. July generally has less sunshine than June by about 15 per cent but there is a recovery of about 5 per cent in August (and a recovery of up to 15 per cent in the west where the July reduction is greatest) except at Rosslare where a decline of up to 10 per cent occurs. The increase in August sunshine amounts has positive consequences for the growth of crops.

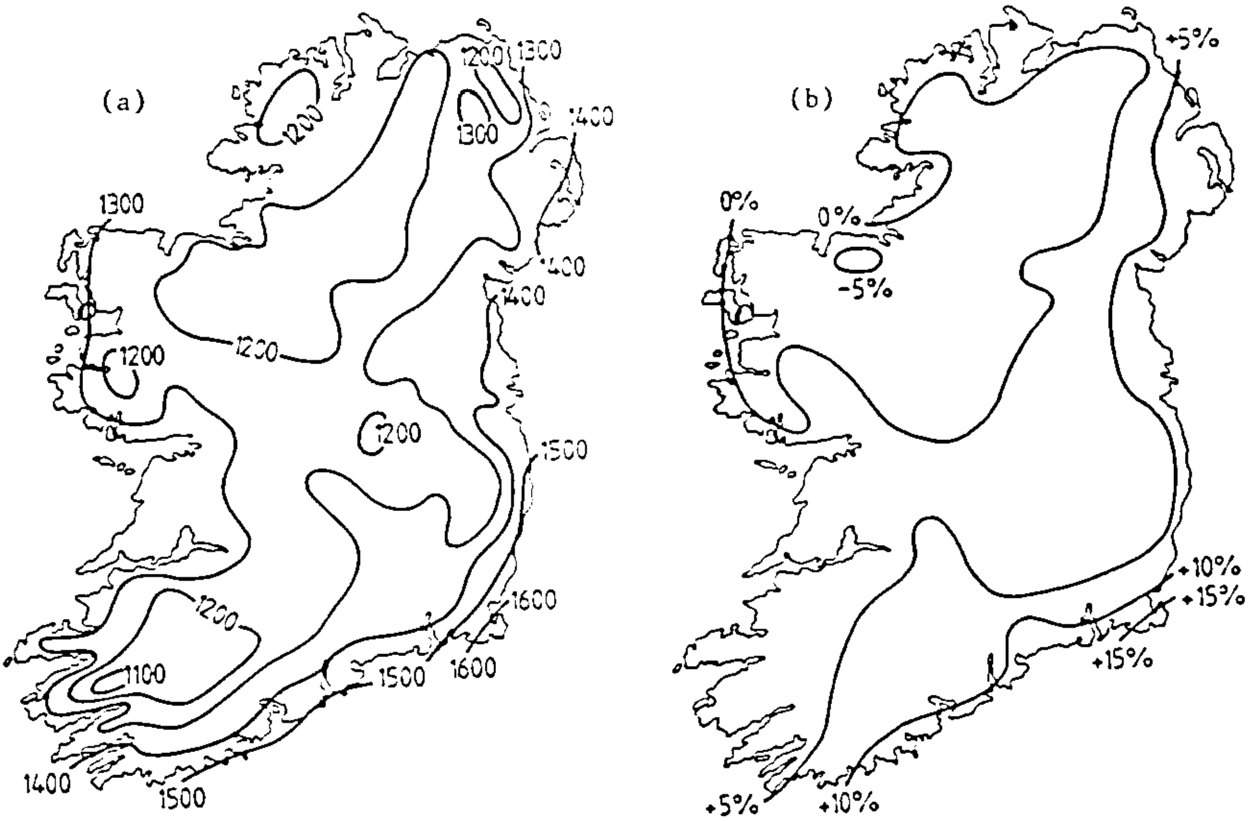

Fig.2. (a) Mean annual bright sunshine hour total, 1951 - 1980
(b) Percentage change sunshine amounts from spring to summer

Water Balance

Annual Precipitation

Of all the elements, precipitation is certainly the most variable in this country. The yearly amounts of precipitation show considerable fluctuation. For example, whereas the mean annual rainfall at Roche's Point, Co. Cork, is 934 mm, the yearly totals in the period 1951-'80 have ranged from a minimum of 685 mm in 1975 to a maximum of 1260 mm in 1958 (Table 6). In nine years out of ten, the annual total at Roche's Point does not exceed 1,112 mm, similar to the average yearly amount at Killala, Co. Mayo.

While rainfall amounts increase with altitude there are also exposure and shelter effects which can to some extent invert the normal altitudinal gradient. For example, west of Croagh Patrick,Co. Mayo, annual precipitation at Delphi Lodge (elevation 32 m) is 2542 mm while at Derryhillagh (104m) on the leeside (of the prevailing winds) the amount is 1533 mm.

Table 6 Annual Precipitation Differences (1951-1980)

Station	Mean	Maximum (year)	Mininum (year)	Max. amount in 9 of 10 years
			mm	
Roche's Point Co. Cork	934	1260 (1958)	685 (1975)	1112
Killala Co. Mayo	1122	1416 (1954)	944 (1971)	1248

Seasonal Precipitation

Rainfall in Ireland does not have a well defined dry period or wet period as in continental countries. Some differences occur however, which are important to farming. These differences are not negligible from an agricultural point of view as can be visualised from Table 7. There is a substantial decrease in precipitation from winter to spring and a strong recovery from summer to autumn at all stations, but there is a tendency for rainfall to be higher in spring at southern stations than in summer whereas the reverse position holds for stations to the north and east. Amounts at Kilrush and Clones in spring and summer are quite similar. Nevertheless Kilrush is 51% wetter in the autumn than Phoenix Park it is only 16% wetter in spring.

Table 7 Seasonal and Annual Precipitation (mm) at the given stations

	Alt(m).	Winter*	Spring	Summer	Autumn	Annual
Ballinrobe	30	360	234	244	369	1206
Clones	89	250	180	227	272	917
Phoenix Park	49	211	163	192	218	784
Kilkenny	66	240	172	172	242	826
Kilrush	24	303	189	227	329	1050
Clonakilty	79	374	246	230	253	1202

* months December, January and February etc.

The Moisture Balance

Soil moisture is the third factor necessary to sustain the growth of plants. As it is not feasible to measure evaporation or evapotranspiration directly at a large number of sites, instruments (e.g Class A pan, Thornthwaite Lysimeter) or energy based formulae (Penman-Monteith, MORECS system(Thompson *et al*, 1981))are used to obtain estimates.

Table 8 Potential Water Balance (mm) *

	P	SD	COV	PE	SD	COV	(P-PE)	SD	COV
Claremorris	1132	106	9.4	409	25	6.1	723	117	16.3
Kilkenny	841	113	13.4	454	27	5.9	387	123	32.1

* Based on data for 1958-'82. P, precipitation; SD, standard deviation; COV, coefficient of variation; PE, Penman evapotranspiration

The gross annual water balances at Claremorris and Kilkenny are given in Table 8. Whereas precipitation amounts have been measured, evapotranspiration totals are derived from the Penman equation for a grass surface. Although Kilkenny has least precipitation, the year to year variation there is greatest as indicated by the standard deviation (SD) and the coefficient of variation or relative variation (COV). The year-to-year variation in Penman values are considerably less (COV, 5-6 per cent) than precipitation (COV, 9-14 per cent). The combined effects on the water balance result in an excess of incoming moisture everywhere which in turn also proves to be very variable (COV, 16-32 per cent). The precipitation excess is least in amount but greatest in variation at Kilkenny suggesting possible insecurity of sufficient moisture in some years at critical periods for drought susceptible crops. Based on evapotranspiration totals given in Thran and Broeckhuizan (1965) annual moisture balance in northwestern Europe varies from less than 100 mm excess precipitation in the east-midlands of England to 30 deficit in northern France (Le Mans).

The number of years when monthly Penman PE exceeded precipitation in the period 1958-'82 is shown in Table 9. Over the winter months, when evaporation is small, only on one occasion in February has a deficit in the monthly balance been recorded. Instances increase during the spring, the superior position at Kilkenny in terms of more frequent occasions with suitably dry soil condition for tilling operations, for example, compared with Claremorris is apparent. However the high frequency at Kilkenny in summer months suggests that soil moisture deficits may be a limiting factor there in many years for crops vulnerable to a large moisture deficiency as was indicated in Table 8.

Table 9 Number of occasions in Period 1958-'82 when Monthly Penman Evapotranspiration Exceeded Precipitation

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	No of occasions in 25 years											
Claremorris	0	0	0	0	6	11	15	9	2	0	0	0
Kilkenny	0	0	1	4	13	15	20	21	13	4	0	0

Working Days

The making of hay depends on evaporation and rainfall during the drying process in the swath. Thompson *et al* (1985) studied the climatic potential for successful swath drying in north-west Europe between May and September (Fig 3). There is a strong northwest to southeast gradient. While Aldergrove is the only Irish station included in the study inference for other stations in Ireland may be approximated from the distribution ih the number of days with rainfall less than 0.2 mm, the relative differences in runs of 5 such consecutive days, and from monthly Penman values, May to September. While Ireland in general does not compare well with Europe, western areas in particular are at greatest disadvantage.

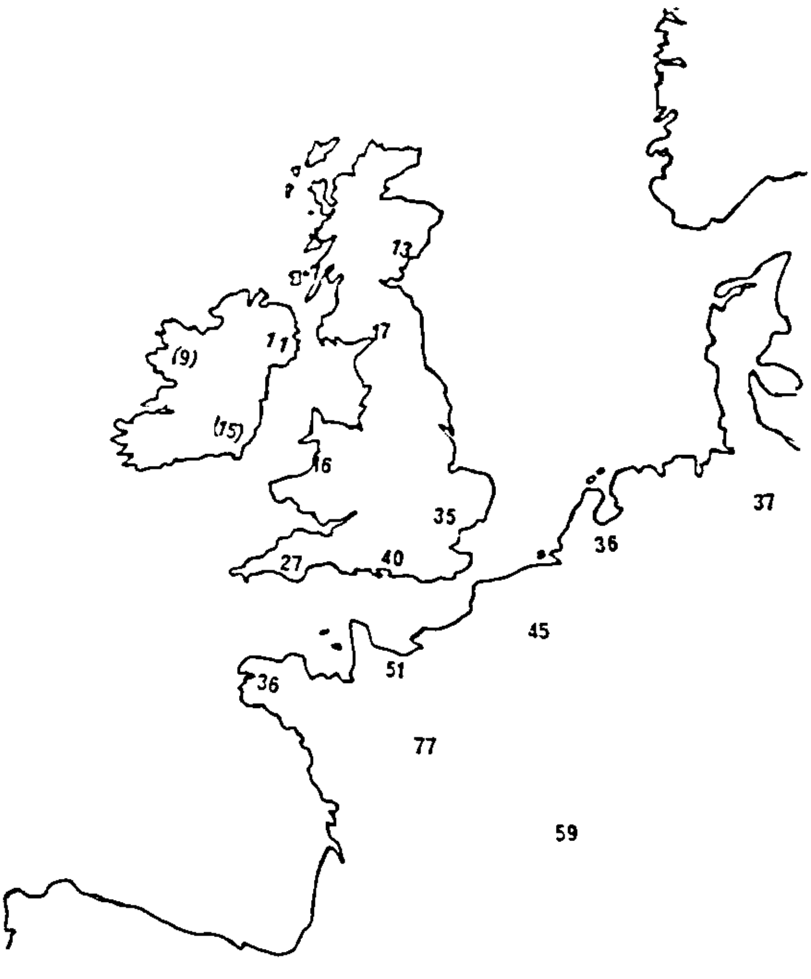

Fig.3. Climatic potential for successful swath drying (from Thompson *et al.*, 1985)

Spring often proves to be a very variable season in terms of a succession of cold showery spells and warm wet spells. Northerly winds become prominent while southerly winds decrease in frequency. Greatest year-to-year fluctuation (COV) in monthly precipitation occurs in April in southern areas but takes place in May in western areas. O'Kiely *et al* (1987) report lower digestibility values if first cut silage has a delayed cutting date. This is of interest in view of the study by Ward *et al.* (1985) which showed the number of working days for silage making (criteria based on precipitation and soil permeability) in the 15-day period, May 15 to May 29 (Table 10). In 6 years out of the 15 years studied there was a considerable decrease in silage making opportunities in Roscommon compared with north Dublin.

Table 10 Number of Working days, May 15 to M ay 29, at north Dublin and Roscommon, 1970-1984

	Roscommon				Dublin	
Working days	3-6	7-10	11-14	15	12-14	15
No. of years	2	4	5	4	9	6

Westerly winds predominate in summer and summer months have greatest variability (COV) in annual precipitation amounts in the mid-east and southmidlands. This is not entirely surprising as much of the rain is of the convective type and depends greatly on the character of the summer weather. Passing frontal systems on the westerly airflow move steadily through whereas in the less frequent summer southerlies, warm and humid air is likely to envelop the country for more prolonged spells. Because these steady humid conditions tend to be infrequent, a reduced spraying programme for potato blight, for example, can be undertaken based on forecast conditions favourable to spread of the disease. As the southerlies recover in August more humid conditions and less settled weather gradually become dominant. There is increased cloudiness, humidity and precipitation in autumn and sometimes extra tropical storms are steered towards the country.

Field Conditions

Field operations may often be undertaken on days in which there is some rain depending on the task and on rate of the evaporation.Regional differences in the frequency of occurrence of runs of 'dry' days having < 1 mm and < 3 mm precipitation in spring and autumn are shown in Table 11 using data from Claremorris and Kilkenny . The latter station has the advantage in terms of number of 'dry' days and in terms of the longer runs of 'dry' days.

Table 11 Number* of days and runs of sequence 1, 2 and 3 or more days with Precipitation amounts < 1 mm and < 3 mm

	Spring		Autumn	
	Claremorris	Kilkenny	Claremorris	Kilkenny
		<1 mm		
No of days	50	57	41	55
No. of runs	15	15	15	17
Freq. of runs of sequence (1,2, 3 or more) days	(6,3,6)	(5,3,7)	(8,2,5)	(6,3,8)
		< 3 mm		
No. of days	65	71	57	68
No. of runs	15	14	16	15
Freq. of runs of sequence (1,2, 3 or more) days	(5,3,7)	(4,2,8)	(6,3,7)	(4,3,8)

* Average 1958-'86

(Adapted from unpublished frequency tables by D. Fitzgerald)

Duration of the Grazing Season

November precipitation has the least relative variability (COV) of all months in all areas indicating that the month is likely to be consistantly wet from one year to the next. This is important not least because the grazing season ceases usually due to the state of the ground rather than the cessation of growth. Connaughton (1973) showed that southern, western and coastal areas in general were in a more favourable position with respect to the length of the grass growing season in Ireland (Fig 4). However, based on an empirical formula after Smith (1976):

$$L = 29.3T - 0.1P + 19.5 \qquad (1)$$

where T is mean annual temperature, P is mean annual precipitation, and L is length of the grazing season, a different picture emerges (Fig 5). While the formula is limited, e.g. it is very general and soil type is not considered, nevertheless the distinct northwest gradient is realistic, the shorter grazing season occurring in regions of greatest rainfall.

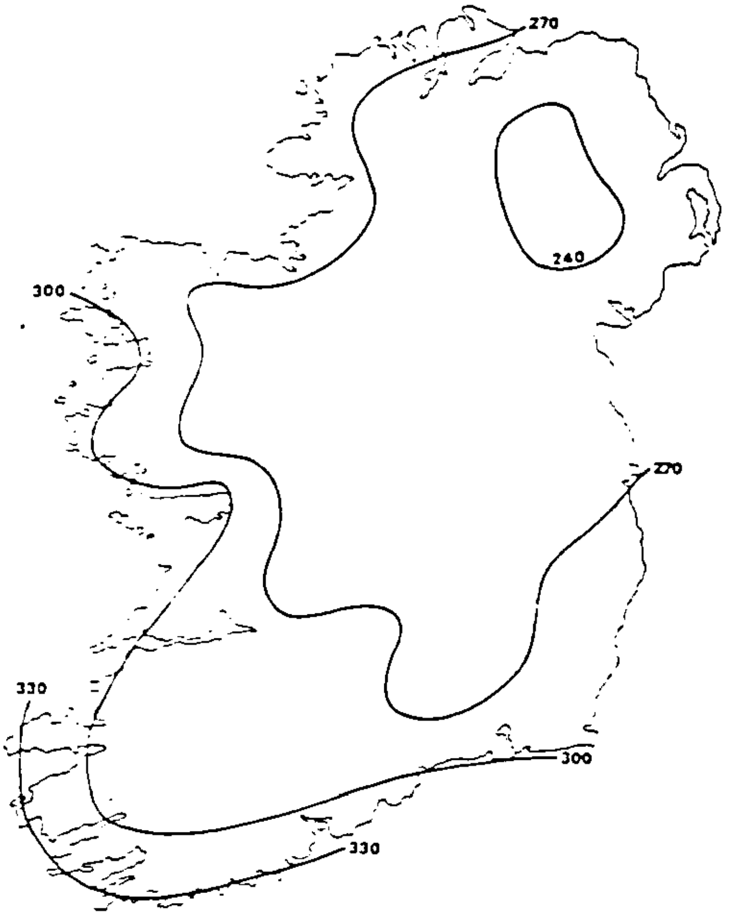

Fig.4. Median length of the grass growing season (after Connaughton, 1973)

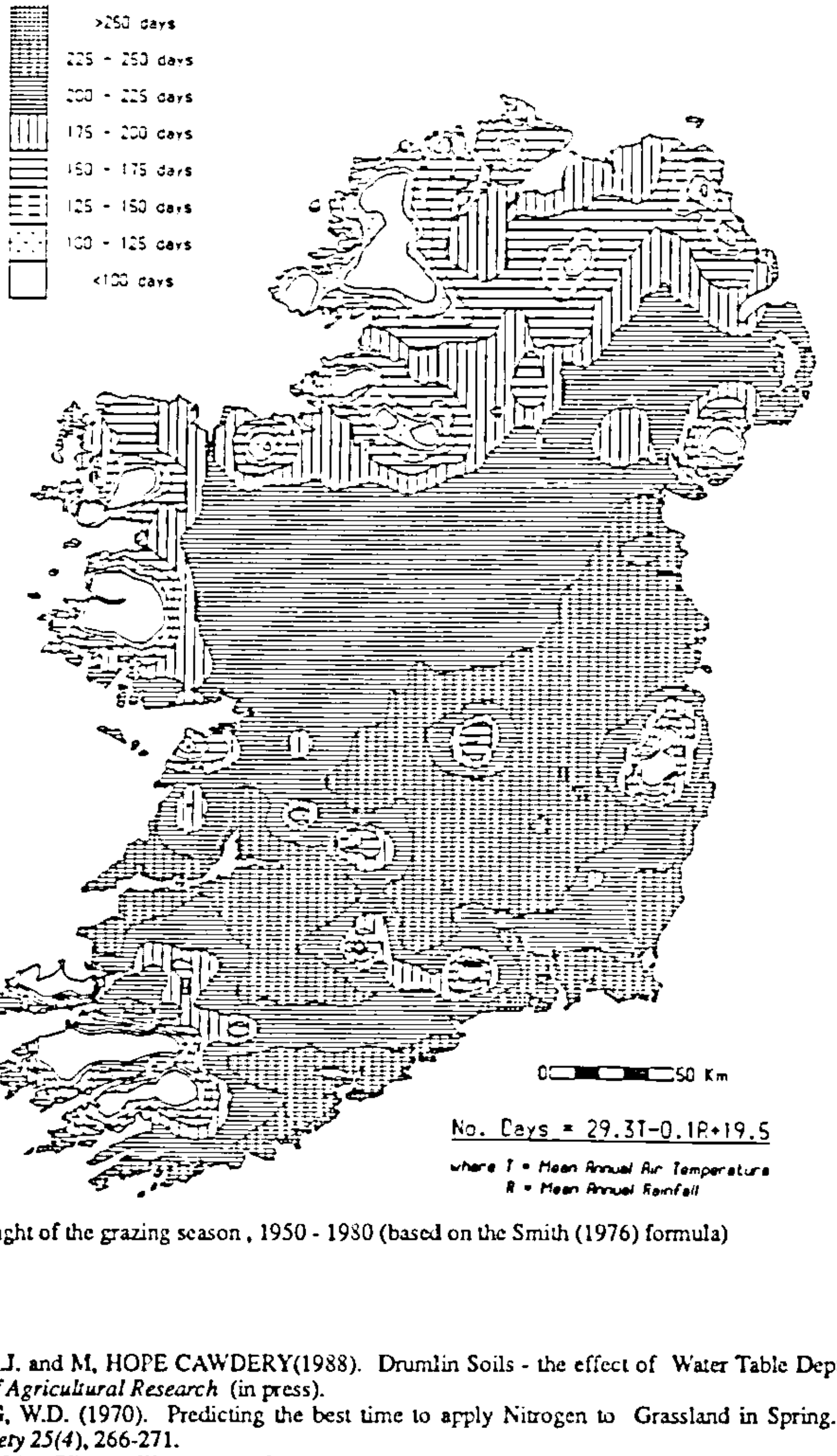

Fig.4. Mean lenght of the grazing season, 1950 - 1980 (based on the Smith (1976) formula)

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EFFECTS OF CLIMATE ON SOIL PROPERTIES AND PROCESSES

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Abstract

Plant life is dependent on stocks and flows of nutrients, and solid provide the medium through which nutrient transport and energy conversions take place. Water, air and energy are transmitted from the external environment to the soil environment and from there to seeds and plant roots, preferably at a rate and in a manner conducive to optimum crop growth and establishment. To be absorbed by growing plants a wide variety of nutrients must be dissolved in soil water and be continuously available at plant root surfaces. The main physical processes common to climate and soil include water infiltration, hydraulic conductivity, evaporation, gaseous exchange and thermal diffusivity and conductivity. Soil properties associated with these processes are surface roughness, structural stability, pore continuity and rooting volume. The nutrient supply to plants is affected by accretion from the atmosphere, rate of nutrient release from soil constituents, fertilizer inputs, nutrient losses (leaching, volatilization, run-off) and nutrient movement within the soil. It is the aim of good soil management to optimise the physical and chemical characteristics of soils, having regard to current and future weather trends. Timing of cultivations, installation of drainage or irrigation systems, maintenance of organic matter contents, application of nutrients, and many other management decisions require an in-depth knowledge of soil and weather conditions specific to each soil and each locality.

Introduction

Optimal physical and nutritional conditions in the soil throughout the season is a prerequisite for healthy growth of crops to maturity. Achieving an optimal environment for growth, however, is difficult because (i) many properties of soils (especially those of a physical nature) are unchangeable, (ii) one soil property, whether physical or chemical, is not necessarily independent of other soil properties, e.g. maximal response of crops to chemical/fertilizer amendments can only be obtained where all physical constraints to growth have been removed and (iii) the efficacy or otherwise of particular management inputs is greatly dependent on prevailing or future weather conditions.

In comparison with animals, crops are immobile so that the mixture of nutrients (including 0_2 and CO_2 gases) essential for growth and development must be present 'close' to where the plant is growing. Since plant roots only occupy 5 per cent, at most, of soil volume under field conditions, the basic problem from a nutritional point of view is how to get these nutrients to the absorbing surfaces of plant roots. Furthermore, soil conditions must be such as to facilitate re-supply of the nutrients to these surfaces once depletion, through crop uptake, has occurred.

The amount of nutrients available for uptake and utilization by crops (including grasses) is the difference between total inputs into soils and total outputs from soils. Aside from the supply from natural reserves in the soil, inputs include (a) depositions in rainfall, (b) fixation of atmospheric nitrogen by leguminous plants, (c) conventional fertilization and (d) additions of farm-yard manure, animal manures, return of unharvested crop residues, *etc.* Outputs refer to nutrient losses from the soil-plant environment and include leaching/run-off and volatilization. Prevailing weather, or climatic conditions generally, affect all of these processes in varying degrees. More subtle effects of weather are apparent, however. It is clear, for example, that there is a direct dependence of biological activity in soils on air and soil temperatures so that weather conditions strongly influence the suply of S. P and N from soil organic matter decomposition.Transient changes in nutrient availability (without actual loss of the nutrients from soil) are also weather-related phenomena, e.g. short-term deficiencies of K or trace elements under drought conditions.

Nutrients inputs to soils

Depositions in Rainfall

Current interests in the chemical characteristics of rain derives from its relative acidity - the acid rain question. However, rain may also be rich in S, N, K, Na, P, Cl and Ca. At the present time we can only guess at the likely significance of these additions in crop nutrition. Heretofore, the contribution of S from rain was thought to balance the S budget of soils. The implication of the latter-day inclusion of S in fertilizers, though, is that rainfall generally does not replenish the soil reserves of S in adequate amounts from crop (grass) growth - at least in some situations. In specific terms, too, little is known about the nutritional significance of K depositions although it may be safely assumed that K-bearing rainfall is more likely to be beneficial in the western parts of the country (where there is rather little use of K fertilizers) than in the east and southeast where the bulk of K fertilizer consumption occurs.

Fixation of Atmospheric Nitrogen

The financial and agronomic importance of legumes in the N economy of grassland has been well established, with estimates of N-fixation varying from 600 kg $ha^{-1} yr^{-1}$ (New Zealand) to 350 kg $ha^{-1}yr^{-1}$ (UK) to 250-300 kg ha^{-1} yr^{-1}(Ireland). Maximizing atmospheric inputs of N by the clover-rhizobium association is related to favourable weather conditions on the one hand and to management practices of soil that favour viability of the clover on the other. Light intensity, temperature and rainfall are each important in N-fixation potential, e.g. a minimum temperature of 9°C is required for active fixation while an optimal soil moisture/soil 0_2 balance is also necessary for clover vigour. Performance of clover plants is adversely affected by shading and consequently, 'frequent' defoliation is more conducive to high fixation than is 'less frequent' defoliation. Flexibility in utilization of grass-clover swards is largely a function of soil physical conditions (especially moisture retention capacity) and rainfall. Animal or machine traffic on wet land, particularly during periods of heavy rainfall, will result in rapid deterioration of the clover and to a reduction in N input by the fixation mechanism. Less emphasis has been placed on the use of clover as a N source for soil in the past twenty years or so than had previously been the case. The likelihood, though, is that this situation will be reversed in the future, requiring a heightened awareness of the management problems of legume production. This will be no less difficult for the management of organic farming enterprises than for conventional grass-clover grazing systems.

Conventional Fertilization

High efficiency of fertilizer use depends on the fertilizer nutrients (a) dissolving in the soil water, (b) staying in the soil water and (c) eventually entering the root system at a rate that will sustain crop requirements. As a consequence of nutrient uptake by the root, a zone of nutrient depletion quickly develops at the outer surface of the root following which further uptake cannot take place unless the depleted zone is replenished by nutrient movement from the bulk soil. Such movement occurs by transport of the soil water (soil solution) and/or by discrete diffusion of the individual nutrients contained in the solution. Rapid re-supply of nutrients to the root surface is facilitated when the concentrations of nutrients in the bulk soil solution are maintained at minimal levels and when the structural features of the soil are such as to permit 'easy' flow of soil water and normal metabolic functioning of the root system.

Speedy dissolution of fertilizers in the soil water is not normally a problem since the common fertilizers are water-soluble and soils will usually contain sufficient water for dissolution. Residence time of nutrients in the soil water and uptake of nutrients across the root boundary are closely related. Therefore a farmer must be conscious of the relative ease with which nutrients can be removed from the soil water and root environment. In this regard, the nutrients N, P and K differ significantly from each other. Fertilizer P quickly interacts with soil constituents to render it highly immobile in soils. Thus P is not leached to any significant degree in the 'average' mineral soil, irrespective of prevailing weather conditions. Neither is it subject to loss by volatilization. In general, K fertilizers behave like P in that inherent risk of leaching is small and there are no volatile losses. Nitrogen fertilizers on the other hand are highly susceptible to leaching (principally as nitrate), and, in certain circumstances, to loss by volatilization, each mechanism being influenced by local climate/weather. It should be noted that micro-environmental conditions in the soil partly determine the speed at which nitrate is produced from ammonium or urea fertilizers. A special case of nutrient loss resulting from water movement is that of run-off which will lead to loss of N, P or K according to prevailing circumstances.

Farmyard Manure, Animal Slurries

In principle, additions to soils of nutrient-rich organic materials should not be different to additions of conventional fertilizers, the basic intention being supplementation of the nutrient supply from soil reserves so as to achieve certain yield objectives. Therefore, manures and slurries should be applied to soils at times in quantities that are appropriate to this objective. Commonly though, expediency takes over and these materials are 'dumped' on land, with little regard for crop nutrient requirement and the likelihood of nutrient losses by leaching and run-off. Such losses, which are greater under high rainfall conditions, and from soils of poor hydraulic properties, have led to greater damage to water quality and environmental integrity, generally, than any other 'technological' development at farm level in recent times.

Nutrient Supply from Soil constituents

The constituents of soils that are important in the supply of nutrients for crop use are organic matter and clays. Presence of organic matter is basically determined by local climate although in the short-term, organic matter content varies with land management practices. In contrast, the amount and chemical composition of the clay fraction are inherited features of soils, not subject to short-term variations. Release of nutrients to the soil water from these constituents is weather-related, especially in the supply of N, P and S from organic matter. From a farming standpoint, the seasonal pattern of nutrient release from organic matter is a most important concept. However, quantification of the organic matter decomposition process is not possible because of the uncertainty of future weather conditions and their effects on soil biological activity. This is best illustrated by the occurrence of year-to-year variations in response to S fertilization on the same sites. The most likely explanation is that in some years, decomposition occurs sufficiently rapid to provide adequate S for growth, whereas in other years weather conditions do not facilitate adequate decomposition to maintain S supply.Shorter-term climatic effects on nutrient supply to crops are also observed.

For example, deficiencies of P, K, Cu and Mn in crops commonly occur, brought about by unfavourablly low spring temperatures (P) and unsuitable soil moisture regimes in early summer (K, Mn and Cu). Frequently, and without soil amendments, these conditions disappear as climatic conditions change.

Nutrient losses from soils

Leaching

During the greater part of the year, rainfall in Ireland exceeds evapotranspiration so that there is an inherent tendency for nutrients to be leached from land in drainage water. As indicated above, however, nutrients are not similar in regard to leaching susceptibility. Among the extential elements, N (as nitrate) and Cl are at one extreme (highly leachable) and P (minimal leaching) is at the other. Loss of nitrate is the most critical issue. For given weather conditions, soils of 'low' clay content will lose more nitrate than soils of 'higher' clay content. Degree of leaching is also directly related to the amount and intensity of precipitation - a given amount of rainfall over a two day period (say) will cause greater loss than the same amount of precipitation over a six day period (say). Because leaching does not commence until soil moisture content exceeds field capacity, the moisture status of the soil at the start of a rainfall event is also an important factor in the leaching process.

Lack of surface permeability in soils on gentle slopes facilitates run-off. In these situations, significant lateral water movement across the soil surface will occur during/immediately following rainfall, carrying with it dissolved/partially dissolved fertilizer salts and manures that lie on the surface. The most prominent example of susceptibility to run-off is the Drumlin area of the north-central and north-western counties.

Since nitrate derived from organic matter decomposition is as likely to be leached as nitrate derived from fertilizers, the extent of leaching is only partly controllable by the grower. In practice, though, application of N fertilizers should take account of the likely future rainfall pattern and of the notion that plant roots have to compete with the leaching process for the added fertilizer. In this regard, early or late fertilization tends to favour leaching because of the adverse effects of lower temperatures on root growth and the plant's general metabolic activity.

Volatilization

Nitrogen losses from soil by volatilization involve emissions of ammonia and of nitrogen oxide gases (NOx's). In the former case, the origin of the evolved ammonia may be animal manures and urea or amonium-based fertilizer. In the formation of NOx's, the substrate is nitrate, either from fertilizers or from soil organic matter.

Ammonia loss from surface-applied animal manures is receiving increasing attention from the environmental perspective. The phenomenon is not site-specific but is affected by prevailing weather conditions such as temperature, wind, *etc.* Ammonia volatilization from surface-applied ammonium and urea (particularly) fertilizers is site-specific, however, and is also influenced by soil moisture/soil temperature interactions. On soils susceptible to volatilization losses (CEC < 18 meq/100g, approx.) rate of volatilization increases with increasing ambient temperatures and decreases with increasing soil moisture content. Under field conditions, the moisture content most likely to maximize volatilization is that which is high enough to dissolve the fertilizer granules but not high enough to dissolve the escaping ammonia gas. A general categorization of Irish soils susceptible to ammonia evolution has been made, but there are no field data which quantify the losses.

Similar comments apply to N losses resulting from the chemical/biological conversion of nitrate to NOx's, although in Ireland a value of 10 to 20 per cent loss has been reported when CAN was applied for early grass in 'wet' years. This value is in general agreement with more comprehensive UK data. Anaerobic conditions in the soil as a whole or, more probably, in discrete microzones of the soil, is the predominant feature of NOx emissions.

Soil physical properties

The foregoing discussion of soil chemical and nutritional properties highlights the need for optimal soil physical conditions. The pertinent physical attributes in this respect are (a) a stable structure with a favourable balance of macro- and micropores and fissures, (b) good air and water relations and (c) a soil temperature regime conducive to biological activity. Both during and outside the actual growing season, soil must be capable of withstanding the effects of machine and animal traffic necessary for preparation, harvesting, transport and other activities. The influence of climate on topsoil properties is often quite obvious but climatic influences on subsurface soil conditions are not so clear. The steps to be taken by the grower to take advantage of weather conditions vary with the season and the crop.

Soil Structure

Whether used for cultivated or pasture crops, soils should have a stable structure capable of maintaining a wide range of pore sizes. A macropore volume of approximately 8 to 18 per cent is needed to facilitate air and water percolation and transport. Soils with macropore volumes of less than 8 per cent are likely to have compaction and drainage problems and be restrictive to taproot extension.The' diameter of pores capable of allowing good root penetration, oxygen diffusion and water movement is 100 mm (approx.). Pores should be continuous to the surface.

Soils must also have an adequate capacity for storing water and for this purpose a substantial proportion of its pores should have a diameter of 50 mm or less. This ensures that much of the infiltrated water is retained in the root zone. Ideally 15 to 20 per cent of the soil volume to the depth of rooting should be occupied by water so that in times of low rainfall, water stress is mitigated or avoided. In general, infiltration rate is increased and available water capacity is reduced by tilling. Well managed and biologically-active pasture soils have both an adequate rate of infiltration and an adequate water storage capacity. Crusted tillage and poached pasture topsoils are both poorly permeable to rainwater and restrictive of evaporative losses.

Soil structure is one of the few soil physical parameters subject to easy modification by managerial practices. The major characteristic influencing development and maintenance of structure is organic matter content. There is usually an inverse relationship between organic matter levels and structural stability of mineral soils. The increasing incidence of slaking, crusting and subsurface compaction reflects a downward trend in the organic matter levels of tillage soils. The incorporation of plant residues, green manures and rotations involving grass are traditional ways of maintaining and improving structure, whereas repeated cultivations facilitate the humification/oxidation of organic residues.

Transfers of air, water and energy at the soil-atmosphere interface depend on the geometry of the soil surface. In recent years much emphasis has been placed on soil roughness and its quantification. Incidences of soil crusting and its associated effects (e.g. poor seedling emergence, water run-off and lack of gaseous interchange) have led investigators to study the role of weather on short-term changes in soil surface geometry.

It was widely believed until recently that soil crusting/sealing only developed under conditions of high rainfall, where large droplets with high terminal velocity caused breakdown of aggregates and sorting of constituents. It is now established that in soils of low organic matter contents and weak structure, slaking follows wetting, even in the absence of significant raindrop impact. On drying, the slaked surface 'sets' in a hard crust, with a smooth upper surface and few pores other than widely-spaced cracks. If crusts are subsequently re-wetted by rain they will soften, but are likely to re-harden on drying. The detrimental effects of crusting on crop establishment depends on the synchronous development of crusts and seedling emergence. While a selection of natural and artificial anti-crusting amendments are available, the most realistic managerial response to the problem is to reduce the number of cultivations and to increase the amount of organic matter.

Soil Temperature

The soil mantle acts as a major storage reservoir for heat. On an annual basis it stores heat during the summer and releases it to the air during the winter; diurnally, it acts as a sink for heat during the day and a source of heat during the night. Characteristics which control/govern the transfer of heat in and from soil include albedo, thermal diffusivity, heat capacity and thermal conductivity. Soil temperature, in turn, affects seed germination, seedling emergence, root growth, nutrient availability and plant development. Indirectly, soil temperature affects plant growth through its effects on soil water, aeration, nutrient uptake and decomposition of plant residues.

In crusted soils the concentration of washed sand grains on the surface leads to high value/low chroma colours which, in turn give the soil surface good reflecting properties. Smooth, light-coloured soil surfaces reflect up to 50 per cent more radiation than rough cloddy surfaces, and dry surfaces reflect about 50 per cent more than wet surfaces. Research has shown that thermal conductivity and heat capacity of soil depend on organic matter, mineral composition, porosity and water content. While a farmer cannot alter the mineralogy of his soil he can influence its temperature by altering organic matter status, porosity and drainage. Various forms of mulching and residue incorporation, as well as fewer tillage operations, will maintain/increase soil organic matter levels while porosity is influenced by traffic and cultivations.

Tillage increases heat exchange at the surface. In spring, when soil warming is important, there is usually a net heat gain in tilled compared with non-tilled soils. Due to higher thermal conductivity, compact sub-soils have a higher temperature during the growing season than deep-loosened ones. 'Early" soils are usually coarse-textured and free-draining, and warm up fairly rapidly in spring, while 'cold' soils are usually fine textured, with a relatively high water content and poor thermal conductivity. Drainage removes some of the excess water and allows such soils to warm more rapidly. Similarly drilled or ridged seedbeds are warmer during the day than seedbeds on the 'flat'.

Frost occurs when the temperature of the soil/plant surface falls to or below 0^{o}C. Its occurrence is more critical to plants than to soil, but its beneficial effects in creating a frost tilth in autumn-ploughed land is often overlooked. Frozen ground behaves somewhat like very dry ground and some farmers try to take a short-term advantage of such conditions to spread slurry and other manures on land. This practice is wasteful of nutrients and likely to cause run-off during a thaw or rainfall event.

Soil Workability

Soil consistence and strength respond dramatically to changes in soil moisture. Most soils are hard and dusty when dry, friable when moist, and plastic when wet. An important criterion is the range of moisture values over which a soil is in the friable state. This in turn is related to clay content, clay type and organic matter content. Most soil manipulations should be carried out when the soil is friable because draft requirements are low, wear and tear are kept to a minimum and compaction, smearing, wheel slip, *etc.* are avoided. It is estimated that the work rate for cultivations in the friable range is 2to3 times that in the hard or plastic ranges. The ability of soil to support machines and animals is greatest in the hard consistence state and poorest in the plastic range. Most poaching damage is done in spring and autumn when strength is lowered at moisture contents above the plastic limit.

The increasing incidence of subsurface compaction in tillage soils is due to working soil at or above its plastic limit. The increased bulk density and reduced porosity are due to external stresses causing deformation, i.e. soil particles sliding over one another into a close-packing arrangement. Compaction manifests itself as cultivation pans/traffic pans/plough pans which in turn affect soil moisture/temperature/air relations and hence yield (both quality and quantity).

Conclusion

The interrelationships between climatic parameters and soil physical and chemical properties are evident in many of the managerial operations/decisions performed during the year by farmers and others. The choice between certain combination of crops is often dictated by the soil's ability/inability to 'handle' the incoming rain, or by the potential of the 'local' climate to provide the degree-day requirement for a full crop. Draining land does not just remove excess water at some periods of the year - it changes soil temperature and thermal conductivity, it modulates the rate of organic matter breakdown and hence the fate of organically-bound N, P, S and other nutrients; it may be the difference between an easy harvest and a difficult or disappointing one.

When a grower applies fertilizers to soil, he is reliant on an adequate amount of rain to wash them in; he expects the nutrients to dissolve in the soil water, enter exchange reactions and/or move towards the roots. He expects the soil to continue supplying water to the plant roots, even during dry spells. If excess rain falls, he hopes it makes its way through the soil and into groundwaters, without carrying nutrients from the root zone. Maintaining organic matter levels of mineral topsoils at 5 per cent or more improves structural stability and fertility status. Furthermore, maintenance of minimal organic matter levels improves infiltration and water-holding-capacity, modulates soil temperature fluctuations, reduces the propensity to slake and crust and increases the time-scale over which a soil is .and in a workable state.

Apart from the shorter-term effects of the interactions of soil and weather on crop production we must also be conscious of the longer-term need to conserve soils. In this regard it is important to recognise that the collective impact of declining organic matter levels, crusting and compaction could lead to 'permanent' soil degradation. Overuse or misuse of fertilizers, including animal manures, has equally serious implications for the integrity of our natural resourses - air, water and soil. A greater understanding, a common vision and a unity of direction are fundamental to making the best uses of these fragile resources. Land use for profitable production of crops and livestock can no longer be viewed in isolation from the wider community's aspiration to live in a clean and wholesome environment.

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THE PLACE OF WEATHER FACTORS IN DEVELOPING RELIABLE PLANT DISEASE FORECASTS

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Abstract

All aerial fungal pathogens causing disease in crop plants depend in some degree on weather for their development and spread. This dependence has frequently been exploited in attempts to produce methods for short-term forecasting of disease outbreaks, development, or some phase(s) of the pathogen life-cycle which relates closely to the severity of subsequent disease. Epidemics of certain diseases, such as cereal rusts and mildews, show a more or less continuous progression in crops and are less influenced by weather fluctuations than other diseases, such as Septoria, Rhynchosporium and net blotch, which progress discontinuously; their explosive nature is due to a qualitative influence of weather, usually as some form of water variables, on one or more phases of the disease cycle. Many past forecasting attempts have drawn exclusively on weather variables and, in general, they have not worked well. However weather is incorporated, reliable forecasts need to be based on the biology underlying serious disease attacks, and our research at Long Ashton seeks to examine the feasibility of forecast-based control of *Septoria tritici* and *S. nodorum* in wheat based on this principle. Our approach with *S. tritici* couples an asessment of resident inoculum in a crop in spring with monitoring for specific rain-splash dispersal events during a critical crop growth stage (from emergence of leaf 2). There is no correlation between the splash events and any convenient meteorological measure of rain amount, duration or rate; a simple splashmeter has therefore been designed and being used to indicate when relevant splash events occur. We are currently investigating with ADAS the possible value of monitoring rainfall by radar, which is based on drop size. So far, our approach to forecasting has shown considerable promise for improving decision-making for fungicide selection and timing using a few relatively simple but sound biological observations.

Introduction

All fungal diseases of aerial parts of plants depend on weather in some degree for their development and spread. The extent of this dependence varies with different disesases and where strong it has frequently been exploited in attempts to produce disease forecasting methods.

Diseases which rely totally on some feature of the weather progress discontinuously in crops and are characterised by sudden, explosive attacks; some leaf diseases of cereals such as the Septorias, leaf blotch (*Rhynchosporium secalis*) and net blotch (*Pyrenophora teres*) are examples. In these, wet weather is almost always necessary and it is the pathogen's relationship with water, in some form, which governs its activity (Royle and Butler, 1985). Commonly, the infection phase is asociated with the need for free water and, for forecasting purposes, 'leaf wetness periods' where rain or dew is thought to persist as surface wetness on foliage. Because the amount of infection is often closely correlated with the amount of subsequent disease, some forecasting 'rules' are simple definitions of the wet conditions associated with infection.

Many other diseases, however, progress relatively continuously in crops, either because their development cannot be associated with any particular weather factor (e.g. powdery mildews) or else because the feature of weather on which they are particularly dependent occurs practically all of the time (e.g. the response of rusts to dew). In these cases the interaction between pathogen inoculum and host plant growth is usually of the greatest importance and has to be taken into consideration in forecasting. Before the implications of these different situations for forecasting are discussed more fully, it is necessary to consider briefly the scope and objectives of disease forecasting.

Types of disease forecasting systems

Disease forecasting may operate in different scales of time and space; according to the scale, different sectors of the agricultural community may benefit (Royle and Shaw, 1988). For instance, had the first serious outbreaks in England of barley net blotch in the late 1970's been predictable, not only would farmers have been able more effectively to avert the large crop losses that ensued, but agrochemical firms would have been alerted to an increased fungicide demand and seed merchants would not perhaps have found such a ready market for the then popular, but highly susceptible cultivar Sonja. Such **long-term** forecasts of major shifts in disease patterns **over wide** areas are, however, not easily achieved and in this paper I am more concerned with **shorter-term** forecasting **within local areas**, i.e. within a cropping season (which helps in setting a seasonal control strategy), and within a few weeks or days (which allows tactical day-to-day decisions to be made). These forms of forecasting can be of various features of disease: outbreaks, rates of development, final severity levels, crop loss or some phase(s) of the pathogen's life-cycle (e.g. infection, dispersal) which relates to subsequent disease or damage. They all aim to identify the need to spray by improving the precision of spray choice and timing, and by identifying which and when crops are most or least at risk from yield-reducing amounts of disease. The greatest benefits from a forecast system can be expected in the control of diseases which are sporadic from season to season and place to place, where the value and costs of control are high, where the pathogen latent period is long and where there is knowledge of the relationships of disease to damage.

Weather-based forecasts for individual diseases

The majority of short-term forecasting proposals are for individual diseases, are based entirely on weather variables, and exist as simple rules, guidelines or 'models'. They do not use weather forecasts, primarily because these are considered to be too unreliable, but interpret weather conditions retrospectively and thus try to warn of possible disease changes within the span of one latent period (time from deposition of inoculum to appearance of the next generation of spores) for a particular pathogen. Few of these forecasting methods have been used to help guide spray decisions at the farm or individual field level; in their development consideration has not been given to the problems of integrating them into farming practice. The conception and use of meteorological variables has created particular problems.

Daily rainfall, humidity and surface wetness all feature in forecasting rules for individual diseases. Rules based on **daily rainfall** have been formulated for forecasting, e.g. potato blight, hop and lima bean downy mildews and *Septoria* spp . on wheat (Royle and Butler, 1985). They have mostly been derived crudely by comparing disease records in crops with concurrent synoptic weather measured at nearby meteorological stations. They thus incorporate a very general relationship between rainfall and disease and offer no greater forecast precision than the simplest, arbitrary statements of daily rainfall. However, the most serious criticism of using daily rainfall is that it offers no explanation of the ways in which rainfall influences phases of the pathogen life cycle. The forecast rules are empirical statements of a restricted, and often unrealistic, range of data and therefore inevitably will not be reliable.

Although **humidity** has implications for wetness persistence and directly influences sporulation in many fungi, it has also been used in an empirical manner in forecasting such diseases as potato blight, apple scab, eyespot and Septoria on wheat and net blotch on barley. Forecast rules incorporating humidity therefore suffer from the same criticisms as those with daily rainfall. Additional problems occur from assigning cut-off points to measurements of relative humidity (e.g. number of hours > 75 per cent or > 90 per cent), which can create serious errors because of the imprecision of standard hygrographs. There is also the inconvenience in extracting such information from continuous records.

The duration of **surface wetness** is the most meaningful and popular of variables used in forecasting, because most foliar pathogen require surface water for infection. Forecast rules usually incorporate relationships between the minimum length of the wet period required at different temperatures and a specified amount of infection, which have been determined in growth room experiments. However, the character and persistence of wetness on plants in artificial environments is different from that in field crops. A more serious problem is that periods of surface wetness cannot be measured directly, only estimated with the aid of special instruments (wetness sensors). Thus, although surface wetness is casually associated with infection it can be applied only in an empirical manner. The relationship between wetness on an exposed sensor and that on leaves in crops is unknown as is the way pathogens perceive wetness on foliage. Examples of the use of surface wetness in forecasting include cherry leaf spot (*Coccomyces hiemalis*), hop downy mildew, apple scab (all rain wetness), and barley leaf rust (dew wetness). For some rules, the source of wetness is unspecified, e.g. onion Botrytis , *Rhynchosporium* on barley and *Septoria* on wheat.

Some of the rules based on these weather variables are used by ADAS to issue regional warnings of weather conditions conducive to disease develpment. They serve to heighten farmers' awareness of possible risk but in disregarding the presence or absence of the pathogen they cannot be expected to be accurate and applicable to local situations. Since the variables used are all empirical neither can they be expected to be reliable.

Can reliable forecasting systems be produced: Septoria in wheat?

In whichever ways weather is incorporated into disease forecast methods, reliability will result only from understanding the biology underlying serious disease attacks. The main limiting factors must be identified and quantified and our research at Long Ashton seeks to examine the feasibility of forecast-based control of *Septoria tritici* and *S. nodorum* in winter wheat based on this principle. The following account concerns mainly *S. tritici* (Shaw and Royle, 1986).

Important biology

Observations and experiments have shown that primary inoculum of *S. tritici* arrives in winter wheat crops during a time window from autumn to early winter as airborne ascospores. These infect areas at least as large as 1 ha more or less evenly, so disease foci are not detectable. The latent period of *S. tritici* is long relative to the period of stem extension in wheat. It can vary from 6-12 weeks in winter to 21-30 or so days in May (average temperature 11-12°C) (Fig. 1). Almost all sowings therefore suffer at least one round of secondary infections during persistently wet conditions before stem extension (growth stage 30-31) starts. Most crops have substantial numbers of active pycnidia on dead basal leaves in spring. Pycnidiospores exude from them and require rain for dispersal. Severe attacks of the disease on the uppermost leaves in spring and summer require infection from inoculum near ground level and, indeed, epidemics can often be traced to one or a few rainstorms in which large, high energy raindrops elevate spores to heights of up to 60 cm through the canopy (Royle *et al.*, 1986). Thus, fungicide timing can be improved by knowledge of the relative splashiness of individual periods of rain.

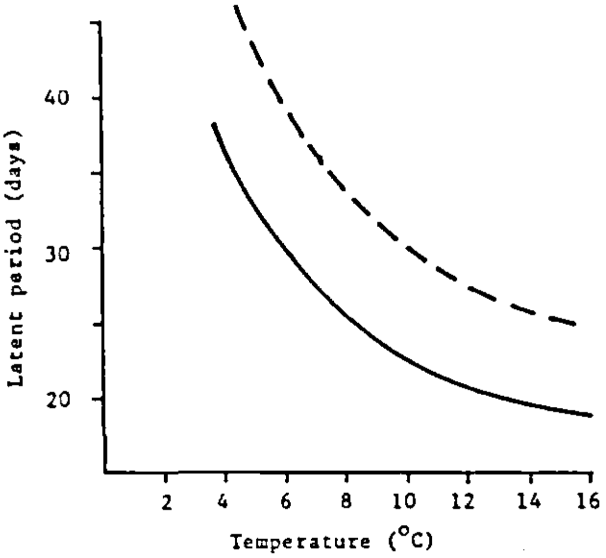

Fig.1. The latent period of *Septoria triciti* in relation to temperature. Solid line; time to first disease after artificial inoculation. Broken line: estimate of time for 50 per cent lesions, after a natural infection event. *cv.* Longbow.

Both theoretical models and simple measurements with a 'splashmeter' show that the extent of vertical transport is poorly correlated with rate of rainfall as measured with a 0.5 mm capacity tipping bucket rain gauge. There is little splash-mediated transport of inoculum in low total amounts of rain (less than *c.* 2mm). This emphasises that conventional meteorological measurements, whether made regionally or in different fields, cannot provide the data needed for good short-term forecasts.

The forecast approach

Fig. 2 shows an experimental scheme for forecasting *S. tritici* based on the crucial biological steps outlined above (Shaw and Royle, 1986). Stage 1 has been developed from our work on the origins and distribution of *S. tritici* in crops. We have developed a simple method to determine the potential risk of individual fields to attacks in summer. This is done by assessing the number of spores produced in dead leaves at the base of plants in spring, at about GS 30-31. If the number of spores per shoot is below a threshold value, then, since there can be no further ingress of *S. tritici* in a crop subsequently, we hypothesise no risk to the crop and no control action need be taken for the remainder of the season. If the number of spores per shoot exceeds the threshold value, then the scheme proceeds to stage 2, which is based on monitoring the 'splashiness' of rain. This is measured by catching dye splashed from dishes on the ground on to absorbant paper above it. A 'splashmeter' has been designed and built for this purpose. Rainstorms and showers can be compared with each other by comparing the heights reached by the drops of dye splashed on to the paper. Monitoring starts once the penultimate leaf (leaf 2, when flag = 1) is at risk because the aim is to protect the top two leaves of a crop upon which the great majority of yield is built. If dye deposits indicate that rain is likely to have caused a lot of spore movement and the crop has not been sprayed recently, then spraying with a suitable fungicide is recommended.Monitoring finishes about 3 weeks before the flag leaf would naturally die, since *S. tritici* can infect only green tissue.

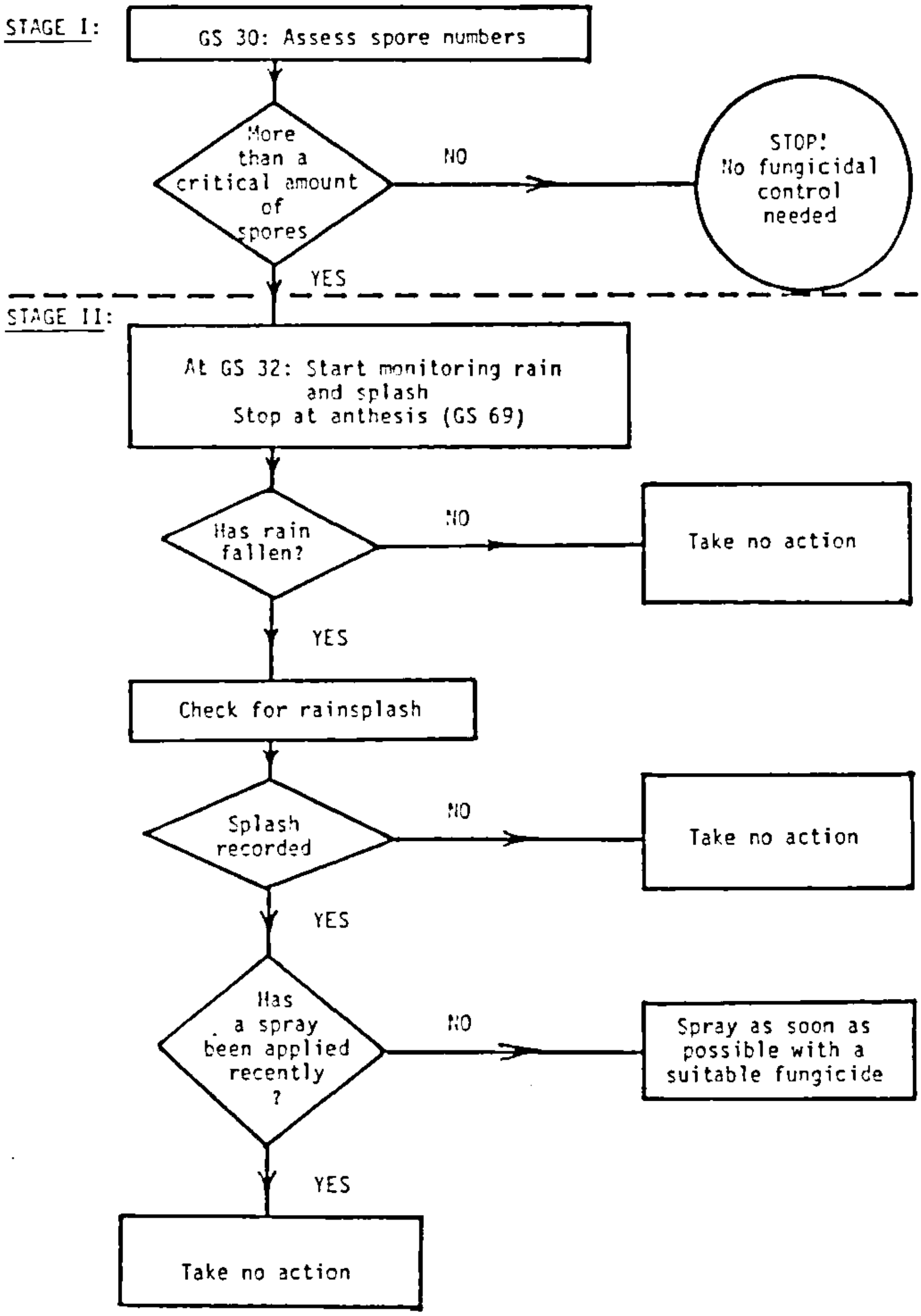

Fig.2. Experimental forecasting scheme for *S. tritici*

Evaluation

During the last two years we have been exploring control of *S. tritici* using this scheme at several sites around the country; some trials are in collaboration with ADAS, and in 1987 ITCF also tested the approach at 5 sites in France. Universally, sprays seem to be timed well by the system, achieving good disease control, but the levels of disease which develop in unsprayed plots at some sites are unexpectedly low, even on the most susceptible cultivars. The causes of this discrepancy from prediction are not yet known but are thought to be associated with the omission from the scheme of the infection phase, which we are investigating.

Conclusions

Our approach to forecasting is based on a few relatively simple but sound biological observations. The method has shown considerable promise for improving decision-making for fungicide timing. We need to incorporate *S. nodorum* into the approach whose biology is similar to *S. tritici* in some respects but different in others. If forecasting Septoria can then be shown to work we need to address the problem of obtaining the right sort of weather information. Electronic weather stations will not help in this situation. Indeed their value in disease control generally as been oversold (Royle, 1985). Concern has rightly been expressed at the arbitrary interfacing to meteorological sensors of several of the simple forecasting rules described in this paper which are empirical, untested and not obviously applicable to local situations. The Septoria approach shows that standard meteorological measurements may not be appropriate. Either a simple, practical alternative like the splashmeter may suffice or else some new interpretation of splashiness, such as might be provided by radar rainfall, which depends on drop size, may well offer scope for more widespread use. Although these and other developments in disease-management schemes (Royle, 1985) are encouraging, new disease forecast methods embracing integrated control of several diseases within a crop system need to be produced. However, they should embrace the mechanistic meaning of meteorological and biological factors to pathogens' response in crops.

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ENVIRONMENTAL ASPECTS OF IRISH CLIMATE

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Abstract

This paper highlights the influence which our climate has on some important episodes in Irish history. Recent notable weather events are also discussed. The causes of acid rain, its effects on the environment, and the pollutants which contaminate our atmosphere and water supplies are examined. A section dealing with climate change and speculation of future climatic trends is also included.

Introduction

Climate shapes and determines our environment. Not alone has climate made a significant contribution to our landscapes but it continues to have an effect on soil behaviour and on plant and animal production.

By way of introduction I would like to mention some important episodes in Irish history and highlight the role played by our climate and environment.

About 5000 years ago our climate was going through what is known as a 'Climatic Optimum', when mean annual temperatures were around 2°C higher than todays. Oak began to replace pine forests, and the first farmers arrived on our shores. The weather during the Bronze Age was dry and favourable, but a stormier colder period followed with increased rainfall. There was a growth in deposits of peat which brought about the formation of our bogs. There followed an improvement in climatic conditions after about 100 B.C.

The climate of Ireland was suitable for grass production even as far back as Roman times. One of our most famous ancient tales is 'Tain Bo Cuailnge' from which we can deduce the importance of the cattle industry at the time. The basic reason why grass grows so well is the moistness of our climate, and the reliability of the rainfall combined with the moderate summer temperatures. Weather conditions continued to be favourable during the early Christian era. The famous monasteries were built and there was an expansion into Europe of Irish culture and learning. There was another brief Climatic optimum around 1000 A.D. there are records of settlements in Iceland and Greenland where farming was then possible in areas now frozen.

The folowing centuries saw a deterioration in weather. The 13th and 14th centuries were centuries of great variability in climate and with some evidence of storminess, mild winters and high rainfall. Between 1347 - 1351 the 'Black Death' swept through Europe taking with it about a third of the population. The so called little Ice Age was particularly marked in the northern hemisphere during the 15th to 17th centuries when summers were short and winters long and cold. Ireland not only experienced a deterioration in climate but also suffered wars and famine. The climate cannot be held directly responsible for plague and famine but climate does affect organism which carry disease. Man's resistance to disease is influenced by social conditions and nutritional factors which in turn are influenced by the climate.

In 1845 there was a 40 per cent loss of the potato crop due to blight, and the famine which followed started a massive emigration from the land. The summer of 1845 was moist and sunless with shallow thundery depressions crossing the country. Blight again affected the potato crop in 1846 and 1848. The appearance of blight is directly linked to weather conditions (Bourke, 1953).

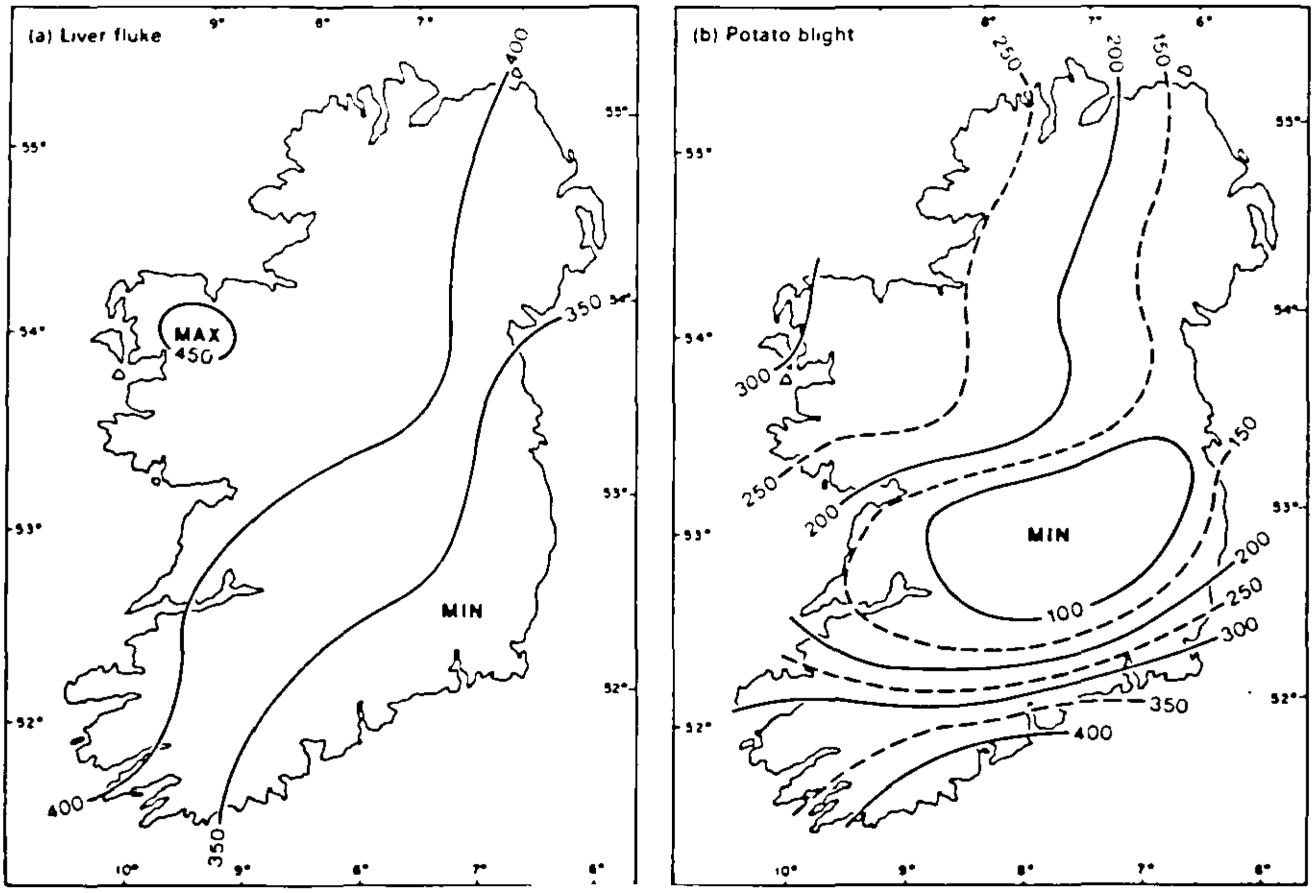

Fig. 1. Areas of Ireland which are most and least susceptible to (a) liver fluke and (b) potato blight.

Fig.1(a) is essentially a measure of habitat wetness, a measure of the excess rainfall over evapotranspiration (Keane, 1986). Fig.1(b) is a measure of the average accumulation of effective blight hours, a lead period of 12 hours with temperature of 10°C or more and relative humidity 90 per cent or more is needed for the formation of the spores.

In historical times the size of the population was directly affected by the climate. In modern times this is probably less true particularly in industrialised countries. However, extremes in climate can result in substantial financial loss. On a global scale, about 40 per cent of this damage is due to flooding, 20 per cent due to tropical cyclones and 25 per cent due to drought (WMO, 1983). The ongoing drought in parts of Africa gives rise to crop failures and food shortages.

Recent weather events of note

In our own country there were a number of notable weather events in recent years which gave rise to hardship in the farming community. There was widespread snow and freezing conditions in January 1982 and January 1987. the Wicklow area was particularly affected. Snow drifts blocked roads and isolated certain areas. A beneficial feature of our climate is that widespread or significant snowfalls do not occur every year, in fact southwestern and western coastal areas rarely experience heavy snowfalls. Many parts of Ireland are only likely to have a fall of snow to a depth of 5 cm once every 2 or 3 years on average.

A cold spell with mean daily temperature 0°C or less, often associated with snowfall, seldom lasts longer than 4 or 5 consecutive days and rarely extends to 10 consecutive days. The most remarkable cold spell in one hundred and fifty years of records at the Phoenix Park, Dublin occurred in January 1881 when mean daily temperatures remained below 0°C for 18 consecutive days (O'Reilly, 1981).

Severe and exceptional thunderstorms in July 1985 were accompanied by heavy hail and rain. Crops in parts of Leinster suffered much damage due to hail and flooding. Stores and outhouses were also flooded. Thunderstorms over Ireland occur on average 4 to 7 days in the year, but storms causing widespread damage, as the thunderstorm of July 1985, are rare. 1986 was a poor year. February was very cold and growth was retarded in the spring(Fig.2(a)). The summer was quite broken with low sunshine values and excess rainfall. Flooding in the Shannon basin, especially in the Leitrim area was well highlighted on television. Blight weather was also well above average in western areas(Fig.2(b)). August was a stormy month with flooding in the southwest on the 5th/6th, and the storm which gained much media attention, known as 'Hurricane Charley', occurred on the 25th/26th of the month. There was much publicity given to the flooding and damage in Dublin, but Wicklow also suffered. Bridges were washed away, trees were uprooted, roads were damaged by landslides, and even whole sections of bog shifted. These heavy rainfalls were accompanied by strong to gale force winds.

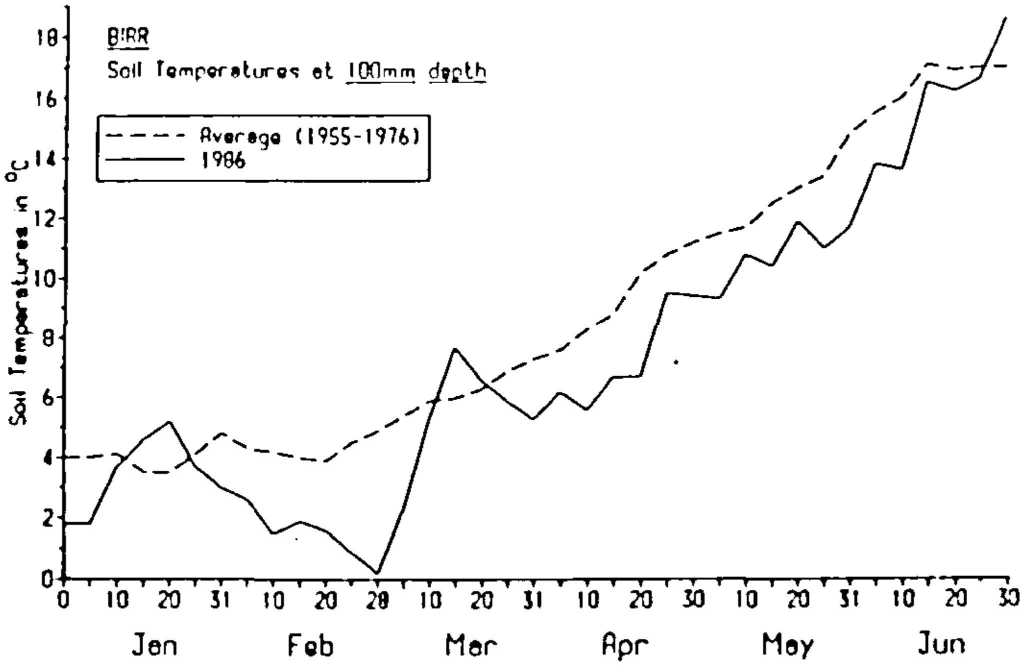

Fig.2(a). Soil temperature in spring,1986,compared to average values

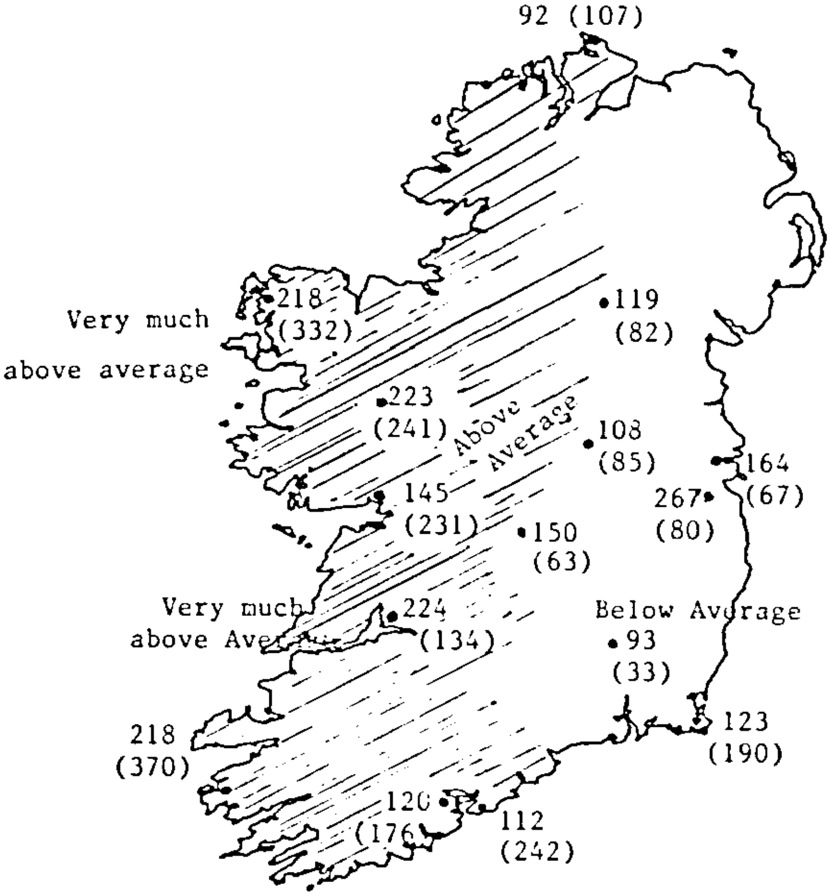

Fig. 2.(b). Effective blight hours, May to July ,1986

Pollution

The pollution of our atmosphere is often directly linked to human activity. Pollution of our air and water is detrimental not only for the financial loss but also for the damage to human health. However, during certain weather situations the risk of pollution is increased, for example during the cold weather an increased use of domestic solid fuel contributes to air pollution. Winter inversions can trap and confine pollutants within a shallow layer above towns and cities. An anticyclone over Ireland in winter usually gives cold settled weather resulting in the formation of temperature inversions, i.e. the air a few metres above the ground is warmer than the air nearer the surface. Clear skies at night allow maximum outgoing radiation and with little or no wind an inversion can become established. Daytime heating causes turbulent mixing which tends to break up inversions, but inversions associated with anticyclonic subsidence can last a few days.

A pollution limit of 250 microgrammes per cubic metre was exceeded during the winter of 1981/1982 (Dublin Corporation,1982) and also in early December 1987 in the Dublin area. The weather during these occurrences was dominated by a cold anticyclone.

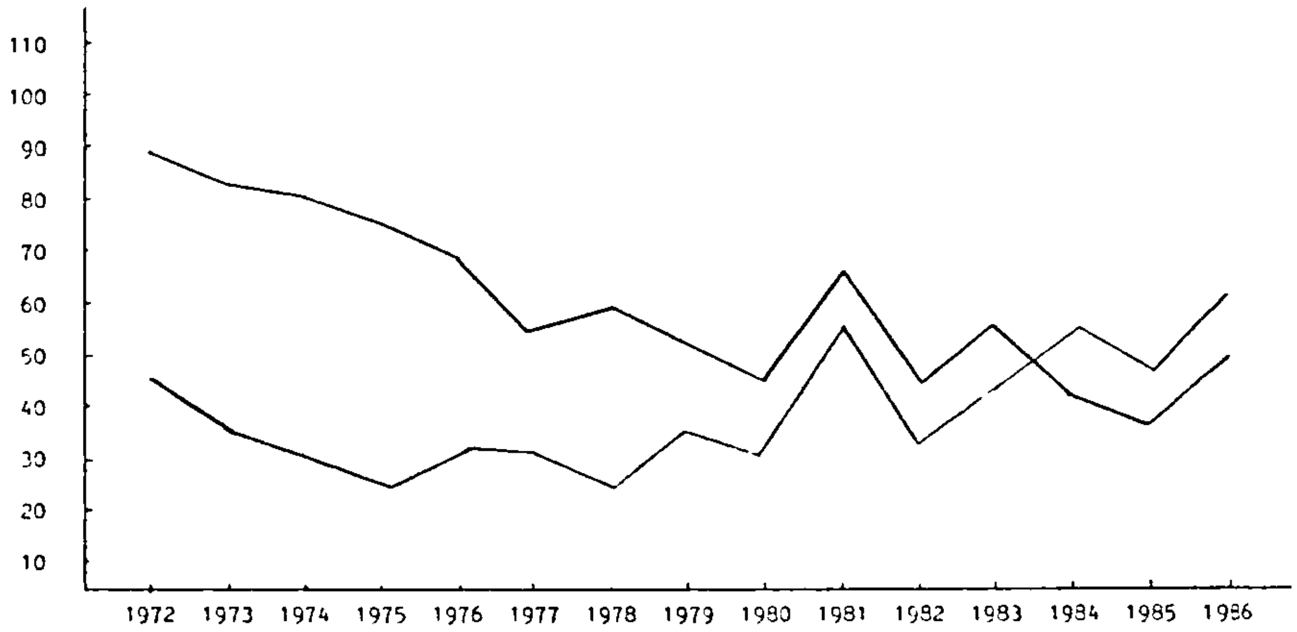

Fig.3. Mean annual concentrations of sulphur dioxide and suspended particulate matter—1972-1986, µg m^{-3}(Dublin Corporation,1987)

Acid Rain

In recent years we have become much more aware of the problem of acid rain. Canada and Sweden are countries very much concerned, particularly as the bulk of the acid rain originates outside their borders. The most concentrated areas of air pollution in the world are over Europe, and Ireland on the fringes can be affected. The long range transport of airborne pollution is well documented. When conditions are favourable deposits of red Sahara dust can be observed in Ireland. If wind conditions are suitable pollutants generated in smoke stacks, oil refineries or other industrial sources in Europe can be the cause of acid rain over Ireland.

The Meteorological Service cooperates with other bodies in sampling rainwater and air. Monthly measurements are made at 9 of our synoptic stations and daily measurements are made at a number, including Valentia Observatory and Rosslare. The network is being extended.

What causes acid rain?

The pH scale is used to measure whether a liquid or soil is acidic or alkaline. A value of 7 is neutral, values above 7 indicate greater alkalinity, values below 7 indicate progressively greater acidity. Normal rain is slightly acidic because of such substances in the air as carbon dioxide. So rainfall with a pH of 5.6 is considered normal and below 5.6 as abnormally acidic. The primary pollutants involved in acid deposition are sulphur dioxide and nitrogen oxides which are the main pollutants emitted from the combustion of fossil fuels.

There is clear evidence that significant acid deposition is associated with rain bearing winds from an easterly direction (Baily and Dowding,1987). It is also clear that rain falling in eastern Ireland in an airflow which has a strong westerly component contain low levels of pollutants. Seasonal trends in pollutant concentrations show seasonal maxima in the late spring and early summer. At Rosslare on 6 different days during October and November last year rainwater samples gave pH readings of less than 4.5. On all but one of these days the wind had a stong easterly component.

At Valentia Observatory 7.3 per cent of the daily samples tested gave pH values of below 4.5 while 1.3 per cent of samples gave pH values below 4.0. These statistics are for an eight year period beginning in 1980 (Caffrey and O'Carroll,1988).

How acid rain affects the environment?

Water with pH of 5.5 or below endangers all species of fish. Certain species of fish have disappeared altogether from some rivers and lakes in Northern Europe. Acid rain affects the forests by attacking the foliage and the roots.

Evidence of the effects of acid rain on trees in West Germany became apparent in the mid 1970s. Many other European countries are now similarly affected. Acid soils and direct attack from the air make the trees more vulnerable to attacks from disease or from severe weather. Severe frosts in conjunction with acid rain may initiate a decline.

Experiments in the United States have found that acid rain can damage the foliage of crops and the yield of certain crops was reduced, radish, beet, carrot, broccoli being some of the crops adversely affected. Conversely because of the fertilizing benefits of the acids some crops showed an increase in yield while others were not affected either way.

Radioactivity

There is also the question of the pollution of our atmosphere due to the release of radioactive material. During the late 50s and early 60s there were high radioactivity counts recorded at times over Ireland as a result of nuclear bomb tests. In recent years levels have been low. For a couple of days in May (Rohan, 1986) the Chernobyl disaster caused radiation counts to be well above normal. Here again weather patterns, especially windflows and rainfall distribution play a major role in the transport and deposition of radioactive materials over us. Even over Ireland some areas fared more badly than others. Animals and vegetables in some areas showed worrying levels of contamination. A point which should be made is that once the food chain is contaiminated the effects may not be detected until long after the event.

River and Groundwater pollution

Two midland lakes, Lough Ennell and Lough Sheelin, suffered from pollution in the early 1970s. There was excessive growth of planktonic algae in the lakes (Toner, 1985). These lakes are renowned for trout angling.

The moisture level of the soil is important when determining how a soil will react to a pollutant, to what degree the pollutant will be absorbed and how much will run off. The number of days when the soil is at field capacity varies somewhat from soil to soil even under identical meteorological conditions. During the months April and May soil conditions may fluctuate many times between field capacity and drier conditions. If land is at field capacity, or frozen, run-off occurs from the spreading of slurry.

Another important factor in determining run-off following spreading of slurry or fertilizer is the time interval between the spreading and occurrence of heavy rain. If there is a heavy rainfall within 48 hours of spreading 30 per cent may be lost in surface runoff (Sherwood,1985).

It can be argued that landspreading contributes only very little to the pollution problem and that the storage and disposal of wastes are much more important factors. However, from the mean number of days with 10 mm or more of rain at widely distributed stations (Table 1), considerable regional and seasonal variation in pollution potential due to climate is evident.

Table 1 Mean number of days with 10mm or more of rain at various locations for period 1960-1984.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
ATHLONE O.P.W.	2	1	1	1	1	1	2	2	2	3	2	2	22
BALLINACURRA	4	3	2	2	2	1	2	2	3	3	3	3	31
BALLYSHANNON (CATHALEEN'S FALL)	3	1	2	1	2	2	2	3	3	3	3	3	27
BELMULLET	3	2	2	1	1	2	1	2	4	3	4	3	27
BIRR	2	1	1	1	1	1	2	2	2	2	2	2	19
CARNDONAGH (ROCKSMOUNT)	4	2	2	2	1	2	2	2	3	4	4	4	31
CASEMENT AERODROME	2	1	1	1	1	1	1	2	2	2	2	2	17
CLAREMORRIS	4	2	2	1	1	2	2	3	3	4	4	4	31
CLONES	2	2	2	1	1	1	1	2	2	3	3	2	22
CUILCAGH MTNS.	7	5	6	3	5	4	3	5	6	7	7	8	66
DELPHI LODGE	10	7	7	5	6	5	5	7	8	10	10	10	89
DUBLIN AIRPORT	2	1	1	1	1	1	1	2	2	2	2	2	19
DUNDALK (ANNASKEAGH W.W.)	3	2	2	1	1	2	2	2	3	3	3	3	27
GLENTIES HATCHERY	6	4	4	2	3	2	3	3	5	6	5	6	49
KILKENNY	3	2	1	1	1	1	2	2	3	3	2	3	22
KNOCKADERRY RESV.NO.1	4	3	3	2	2	1	2	2	4	3	3	3	34
MALIN HEAD	3	2	2	1	1	1	1	2	3	3	4	2	25
MALLOW (HAZELWOOD)	3	3	2	1	1	1	2	2	2	2	3	3	25
MARKREE CASTLE	4	2	2	1	2	2	2	3	3	3	4	3	33
MULLINGAR	3	1	1	1	1	2	1	2	3	3	3	3	24
PORTUMNA O.P.W.	2	1	1	1	1	1	2	2	2	2	3	2	19
ROCHES POINT	4	3	2	2	2	1	2	2	3	3	3	3	29
ROSSLARE	3	2	2	2	1	1	1	2	3	3	3	3	27
ROUNDWOOD (FILTER BEDS)	5	3	3	2	2	1	1	2	4	4	4	5	39
SHANNON AIRPORT	2	2	1	1	1	2	2	2	3	3	3	3	24
SILVERMINES MTNS. (CURREENY)	7	4	4	4	3	2	3	4	5	5	6	7	54
VALENTIA OBSERVATORY	6	4	4	2	2	2	2	3	4	5	5	5	45

During a severe cold spell a question likely to be asked is ..." Are we moving towards another Ice Age?". When the weather is good there is speculation on whether our climate is improving. Records from our long term stations show only small fluctuations in climate in the last 200 years. Scientific evidence for the period 1920 to 1960 indicates that the northern hemisphere was warming both in winter and summer. The graph of mean temperatures at the Phoenix Park reflects this finding. After 1950 temperatures have shown less consistent trends. The 1960s were cooler than previous decades. The early 1970s were warmer than the 1960s but the later years were cooler. The warming trend of the early part of the 20th century came to an end in the 1950s.

Factors which could influence future climate change could be of our own making. Increased pollution of the atmosphere, particularly the effects of aerosols on the atmosphere and the increase in carbon dioxide levels could result in the alteration of the radiation balance. As a result of burning of fossil fuels and changes in land use atmospheric levels of carbon dioxide have been rising. "Will rising levels of carbon dioxide cause a greenhouse effect?" Some general circulation models suggest a global increase of 2 to 4°C. An increase as large as this on present day climate would probably be greater than any change since the last Ice Age. However, the warming in the earlier part of the century and subsequent cooling cannot be explained in terms of increasing levels of carbon dioxide.

Summary

Our climate shapes and determines our environment. Notable historical happenings were linked to changes in our climatic environment during the past 5,000 years. Severe weather conditions cause financial loss and hardship to the community, and a number of notable

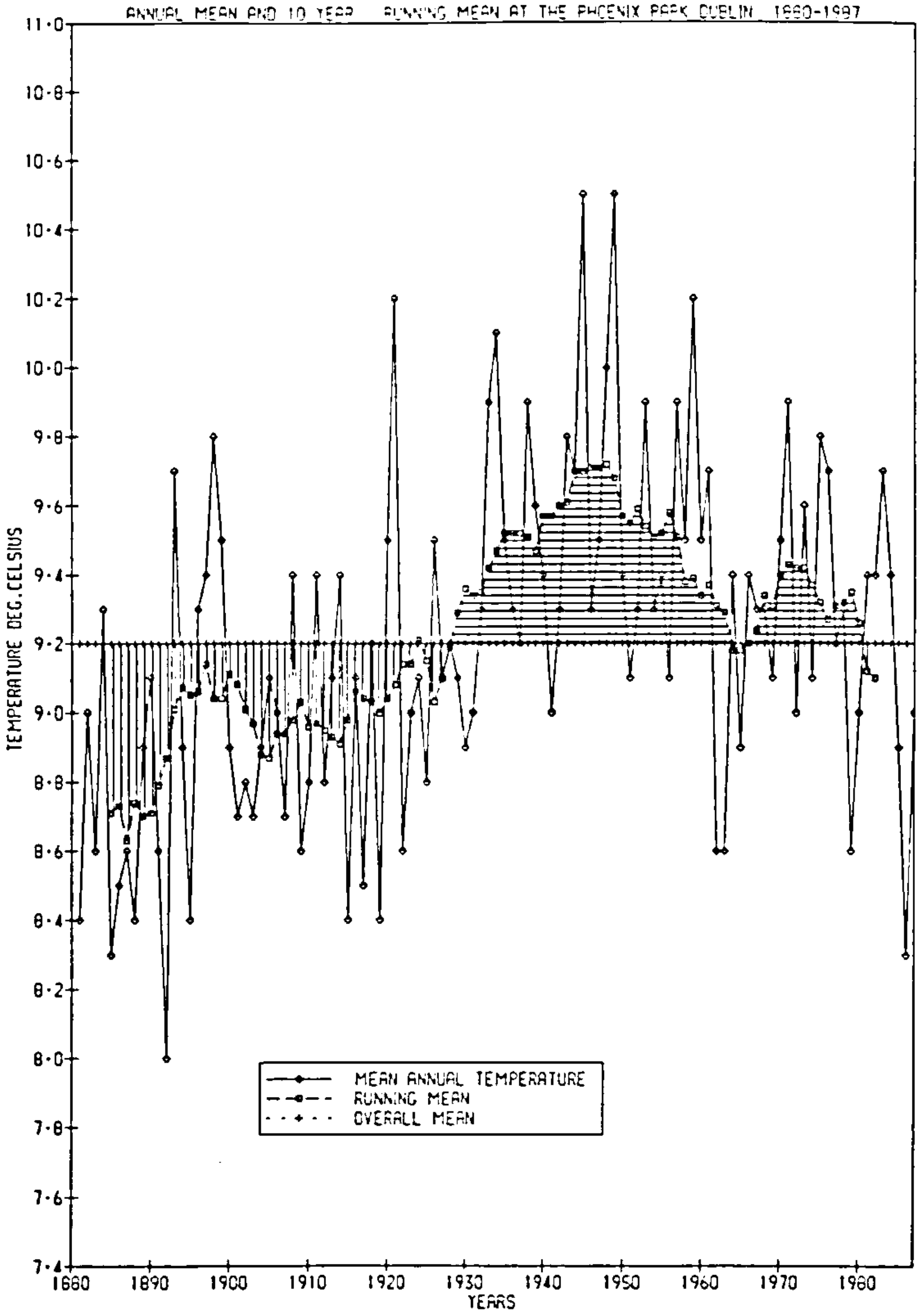

Fig.3. Mean air temperature at Phoenix Park,1880-1987

spells of inclement weather in Ireland in recent years are listed, also some of the benefits arising from our climatic environment are mentioned. Weather patterns can either increase or decrease the risk local levels of pollution, and also affect the transport of pollutants from other areas. The effects of acid rain on trees, plants, fish and on drinking water are also discussed. Field capacity and other meteorological factors are examined with the view of lessening the pollution caused by normal farming activities.

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SIMULATION OF PLANT GROWTH AND DEVELOPMENT

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Abstract

Crop growth models for sugar beet and winter wheat crops are being developed at the AFT Oak Park Research Centre, Carlow. The models function by updating the state of the crop on a daily basis. The dry matter produced on a given day is calculated from the photosynthesis and respiration rates, which in turn are functions of the mean temperature and total radiation on that day. Thus the individual weight increases ha^{-1} day^{-1} for roots, leaves and petioles can be calculated. The dry weights of the plant parts calculated from samples taken in the field are used to start up the model in conjunction with the relevant weather data. The predicted crop growth rates for the past two years were quite satisfactory when compared to actual growth rates recorded at Oak Park Research Centre.

Apart from predicting crop yields, the modelling concept is seen as a powerful means of integrating our knowledge about the performance of crops in Ireland. It also allows for the examination of single factors such as late sowing, or the onset of water shortage and their interactions, while at the same time holding other factors constant. This approach is useful in suggesting possible experimental and analytical avenues for future work. It can also point clearly to where larger gaps lie in the knowledge of the physiology and performance of the crop.

Introduction

In recent years price restraint has been a feature of EC agricultural policy, and as a result farmers have seen rapid escalation in the costs of production without corresponding increases in EC farm prices. Work at Oak Park Research Centre has centred on increasing the production efficiency of arable crops in which the development of computer simulation models is seen as a central element in this approach. At present such models have been developed for cereals and sugar beet.

What is a Model?

The word model is normally associated with miniature working prototypes or toys. However, while crop growth models are constructed in a kind of way like a mechanical device, the components in this case consist of data on crop growth and their interaction with environment. It is important to emphasise that a model of crop growth has to describe the basic processes occurring in the plant and what effect the crop environment has on the rate at which these processes take place. Research results allow for the construction of well defined statements which can then be stored and assembled on computer (Penning De Vries and Van Laar, 1982).

Such an approach provides a powerful means of integrating our knowledge about crops in Ireland and allows for the examination of single factors such as late sowing or the onset of water shortage and their interactions while holding other factors constant. This approach is also useful in suggesting possible experimental and analytical avenues for future work and also closely identifies gaps in our knowledge of crop performance.

Basis for Crop Modelling

In crop growth, solar energy is converted by photosynthesis into plant biomass. During this process CO_2 is assimilated from the air and converted into carbohydrate. Part of the carbohydrate fixed is used as building material for structural plant dry matter and part is used as a source of energy for plant processes. The release of energy from sugars produced during the assimilation process is called respiration and the difference between respiration and assimilation determines plant growth rate (Pening De Bries and Van Laar, 1982; Loomis and Williams, 1963).

In the absence of stresses such as diseases, weed competition or nutrient deficiency, the rate at which the plant growth processes take place is largely determined by soil and climatic factors, of which the most important are soil moisture, solar radiation, temperature, wind speed and relative humidity (Biscoe, and Gallagher, 1977).

The overall modelling process can be represented by the following equation:

$$G = E_c (A_g - R_m W)$$

in which G is the rate of increase in structural dry weight in kg ha^{-1} d^{-1}, E_c is the conversion efficiency in kg (dry weight) kg^{-1} (carbohydrate), A_g is the gross assimilation rate in kg (carbohydrate) ha^{-1} d^{-1}, R_m is the relative maintenance respiration rate in kg (carbohydrate) kg^{-1} (dry matter) d^{-1}, W is the total dry weight of the living part of the crop in kg ha^{-1}. In sub-models, A_g and R_m are estimated as functions of temperature and radiation and other relevant weather variables.

Usefulness of Wheat Model

There is considerable interest in reducing the cost of cereal inputs without necessarily affecting yield. At present the application of nitrogen, herbicides and growth regulators are carried out according to crop growth stage (Zadoks, Feekes) which is generally dependent on changes in leaf and tiller number. These changes are often difficult to determine accurately due to interference of coleoptile tillers and senesced leaves. Furthermore these changes are merely the external results of physiological change, which take place deep inside the developing plant at the apical meristem (Kirby *et al*, 1984; Porter *et al*, 1987).

At Oak Park plant development is being investigated using both field and computer simulation studies (Burke & McGuinness, 1988). The compute simulation of development uses current and long term average meteorological data to predict development and thus indicate when certain critical stages are reached especially the dates at which different varieties reach:

(1) **Double Ridge Stage,** i.e. when the embryo is forming in the stem;
(2) **Terminal Spikelet,** i.e. when all the Spikelet,s are laid down on the developing ear - generally around the time when first node is visible;
(3) **Second Node Stage.**

Discussion

The results from the past three years indicate that the predicted development stages were very close to the observed dates. It is hoped that in the future this approach will lead to more efficient crop management, and it is probable that it may replace certain aspects of the 'growth stage' idea particularly those aspects which are known to be unreliable. This is important for a variety of reasons, for example, some chemicals applied to wheat plants can have growth promoting or deliterious effects. If herbicides containing 2,4-D or MCPA based chemicals are applied to the developing embryo then yield reduction can occur. Alternatively growth regulators can shorten the stem and prevent lodging. Thus in order to obtain maximum benefit from many agricultural chemicals it is important to apply them when the plant is at a precise developmental stage. It should be noted, however, that direct measurement checks using simple dissection tchniques will always be required, as no computer program will be able to deal accurately with every conceivable combination including weather, variety, sowing date, together with local factors such as location/aspect and soil type.

Modelling of crop growth in cereals can be useful not only from a research viewpoint in pinpointing critical limiting factors involved in growth and development but it can also suggest causes for yield variation between different regions. In the past yield variation has ben difficult to separate from management/climate which in certain seasons can be quite substantial. In 1986 for example there was considerable variation in the yield of winter wheat in different regions of the country (Burke and McGuinness, 1987). The computer growth model allowed for an examination of the effect of weather on potential crop growth and indicated that local weather patterns did in fact have a substantial impact on final crop yields.

Growth Models for Sugar Beet

Computer modelling of the growth and development of the sugar beet crop is also likely to play an important role in research planning and in the organisation of crop harvesting and processing in the future. Irish sugar yields rose rapidly in the period from 1950 to 1970, but the period since then has been marked more by large year-to-year fluctuations than by a sustained increase. Unpredictable yield fluctuations from year to year create difficulties for the Irish sugar industry in two ways:

(i) sugar marketing is made more difficult by uncertainty of supply.
(ii) scheduling of the processing campaign cannot be optimized in the absence of accurate information on the volume of beet to be processed.

Crop sampling before harvesting gives an estimate of final yield, but even samples taken at the end of September can give misleading estimates due to variations in subsequent crop growth. Using the many relationships already outlined that exist between the development of the plant and its environment it is possible to develop a crop model which can be used to forecast crop yield more accurately. Among other potential benefits of the model are:

(i) It allows for the factors limiting sugar beet growth in Ireland to be more clearly identified, and research directed towards their removal.

(ii) Makes conventional research more productive by using the model to extrapolate trial results and by defining research objectives more clearly.

The potential sugar beet yields that can be obtained in this country have been calculated using the sugar beet model and it indicates that nationally there is considerable scope for further improvement in raising the national average yields.

Conclusions

In order for the Irish tillage industry to continue into the future more detailed information will be needed to help the grower make more informed decisions so that efficiency can be increased. In this regard it is felt that using crop modelling and improved agronomic techniques significant contributions can be made.

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EFFICIENT PASTURE MANAGEMENT

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Abstract

Variability in herbage production during each year can lead to inefficient utilization - because grazing pressure is not flexibly adjusted to meet variations in herbage available. The adoption of flexible grazing management on farms is hindered by the difficulty of obtaining advance estimates on a day-to-day basis of the volume of herbage available in the system. The paper describes the operation of a grazing control system based on a herbage growth model. Advance simulations of the rotation are provided which indicate the expected number of days grazing available on each paddock. Where the output indicates an expected rotation greater than 25 days then surplus paddocks are identified as candidates for silage cropping. Where the simulation indicates an expected rotation less than 15 days then the need for pasture supplementation and the scale of supplementation required is signalled. The system has been in operation for 3 years. The operation of the grazing control system is basically dependant on the estimates of herbage growth from a herbage growth model. The model is a relatively simple one which estimates growth as a function of radiation received at the crop surface, air temperature and rainfall.

Introduction

The output of animal production from a grassland system depends both on the amount of herbage produced and on the efficiency of its utilization. High efficiency depends on the maintenance of an optimum balance between the herbage available and herd feed demand. The achievement of high efficiency of herbage utilization is hampered by variability in the amount of herbage produced. The number of animals in a system is not usually variable so that variations in the amount of herbage available leads to a sup-optimal balance between supply and demand.

Herbage growth, at a given level of management inputs, is determined by weather conditions. The pattern of seasonal production is predictable in broad terms as a function of the changing weather between seasons and grazing systems are assembled accordingly. The basic objective of systems is to achieve high utilization efficiency by maintaining a balance between herbage available and herbage demand. The balance is usually achieved by adjusting the size of the grazing area progressively during the year. The area not required for grazing is used to create a reserve of forage as silage, that is used to buffer the system when grazing herbage supply is restricted.

System Efficiency

The seasonal changes in weather, and herbage growth, are only broadly predictable. Within this broad pattern there is considerable day-to-day variability. Failure to adjust to these variations leads to inefficiency in herbage utilization. Overall utilization efficiency is the product of the eficiency of harvest and the efficiency of conversion of harvested herbage to animal production. Both efficiencies are controlled by grazing pressure, or herbage allowance (Fig. 1).

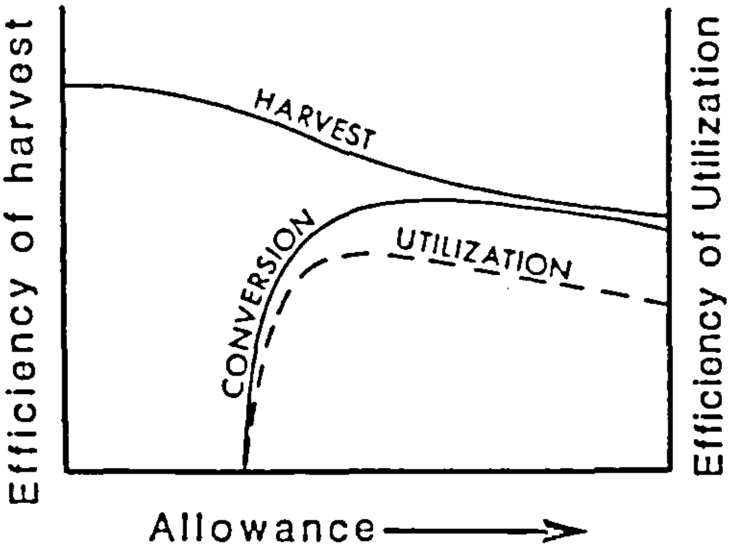

Fig. 1. General relationships between herbage allowance, efficiency of harvest, efficiency of feed conversion and overall utilization efficiency

Efficiency of harvest, defined as the fraction of the standing herbage mass that is harvested, increases as the herbage allowance decreases. The efficiency of conversion, defined as the ratio of liveweight gain and the amount of herbage harvested, is zero at low herbage allowances when there is no liveweight gain. It increases to a maximum at an intermediate allowance and declines at higher allowances as animal performance approaches the potential maximum. The product of the two efficiencies, overall utilization efficiency, is maximum at an allowance less than that required for maximum conversion efficiency (Fig. 1).

It is clear that, to achieve maximum system efficiency, it is important to be able to estimate herbage allowance on a continuous basis during the grazing season. Against the background of short-term fluctuations in weather and growth this is difficult to do. Furthermore, the inter-relationships between animal performance, intake and allowance are affected by herbage mass and by other factors such as the profile structure of the sward. Thus, the assembly of model of this interface between the sward and the grazing animal is difficult.

Two-layer sward model

The basic difficulty in the use of the concept of herbage allowance is that it fails to recognize that all of the total standing herbage mass is not equally available to the grazing animal, nor that all of it is equally digestible. The canopy is more or less clearly separated horizontally into an upper horizon of highly digestible material which is relatively inaccessible by the animal. The height of the boundary between the two horizons can be controlled by grazing pressure (Jackson, 1979). This simple two-layer model of the canopy suggests that the herbage allowance concept may be replaced by the concept of herbage available - defined as the quantity standing above the boundary between the layers. Recent studies in continuously grazed swards have indicated that the rate of net herbage accumulation is not affected by a wide range of grazing pressures (Bircham and Hodgson, 1983). Similarly, under simulated rotational grazing management, the effects of grazing pressure (stubble height post-grazing) and rest-interval between harvests were relatively small (Brereton and Carton, 1986) for the range of heights and rest intervals normally encountered in farm practise. Therefore, the height at which the boundary between the upper and lower horizons of the canopy is set is optional (at least within broad limits) as regards the efficiency of herbage production.

If the sward is always grazed to the same boundary height then harvest efficiency of the available herbage is always 1.0. The utilisation efficiency of the system is then dependent only on the efficiency of conversion of the harvested herbage. Several studies with bovines have shown that herbage intake and animal performance is reduced when sward height is less than approximately 80mm (Le Du *et al.*, 1979), though the height below which performance is restricted probably depends on the profile structure of the canoy. There is evidence that a constant sward grazed height over an extended period can only be achieved when animal performance is restricted. Animal performance is high when the grazed height is increasing progressively (when herbage growth exceeds consumption) and *vice versa* (Alcock *et al.* 1985). At the Johnstown Castle Research Centre, experience with steers, grazing rotationally in perennial ryegrass swards, suggests that steady state conditions can be achieved only when the post-grazing height is 70 mm and animal performance is restricted to 1.0 kg $hd^{-1}d^{-1}$. At this level of animal performance, feed conversion efficiency is not seriously reduced. Thus the system is optimized when successive paddocks are always grazed to 70 mm.

Rotation Management

The application of the two-layer model of the grass canopy, with the boundary between the layers at 70 mm, renders it unnecessary to determine the amount of herbage present before grazing. It is only necessary to observe when all of the herbage has been utilised, i.e. when sward height is 70 mm. This approach to paddock management simplifies the management of individual grazing events but the problem of the management of the full rotation remains. The number of days required to graze individual paddocks to the target height of 70 mm will vary as the amount of available herbage varies. Consequently the number of days to complete a rotation will vary. An excessively long rotation can lead to the accumulation of great herbage masses and to dry matter losses to senescence. Excessively short rotations may lead to a reduction in the rate of net herbage accumulation.

The rotation length (R_i) is determined by the average number of days grazing on a paddock (D) and the number of paddocks (P). Thus:

$$R_i = D.P \qquad (1)$$

The number of days grazing on a padock is determined by the daily regrowth rate (G) since the previous grazing; the length of the previous rotation (R_{i-1}) - which is also the length of the current regrowth; the number of animals in the herd (N); and the daily target intake (I). Thus:

$$D = G.R_{i-1} / N.I \qquad (2)$$

and

$$R_i = G.R_{i-1} .P / N.I \qquad (3)$$

It is evident that the number of paddocks in the system (P) is the only variable available to management for controlling the current rotation length (R_i). When the number of paddocks required exceeds P then the system must be supplemented by imported feed, so that

$$R_i = (G.R_{i-1} + S). P / N.I \qquad (4)$$

where S = feed supplement (herbage equivalent) per paddock.

The total supplement (SP) is the difference between feed demand and feed available. By re-arrangement of (4).

$$SP = (R_i.N.I) - (R_{i-1}.G.P) \qquad (5)$$

The calculated pattern of change in rotation length in response to a typical pattern of change in herbage growth rate is illustrated in Figure 2 for three rotation management strategies. In the first case (curve A) neither supplementary feeding nor paddock number is used to control rotation length in periods of feed deficit (short rotations) or in periods of surplus (long rotations) respectively.

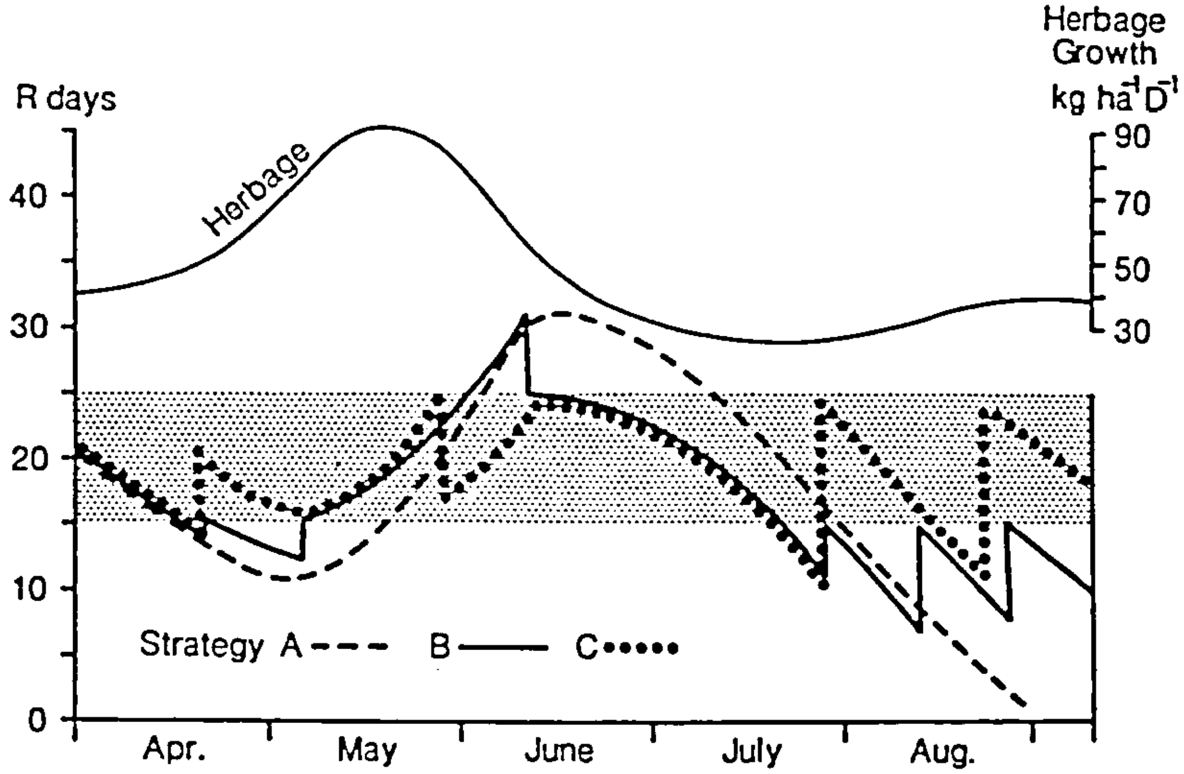

Fig. 2. The effect of herbage growth rate and rotation management strategy on rotation length. Based on equation 4 of text, where P = 10 paddocks (each = 1 ha); N = 83 steers (300 kg liveweight) and I = 7 kg $hd^{-1}d^{-1}$ dry matter. Total system area is 10 ha and the stocking rate of the system is equivalent to 4.8 L.S.U. ha^{-1}.

The rotation length oscillates widely and beyond the target range of 15 to 25 days, with consequent losses of herbage productivity. In the second case (curve B) rotation length is adjusted to 15 or 25 days whenever it exceeds the target range. This occurs on six occasions - an adjustment to 15 days by supplementation in five and an adjustment to 25 days by paddock number reduction on one occasion. In the last case (curve C) a strategy is adopted to minimise the number of occasions on which adjustments are required (4 occasions).

Herbage growth model

The two-layer physical model of the sward and equation 4 form the basis of a paddock grazing control system which is computerised and operating at the Johnstown Castle Research Centre. At weekly intervals the programme provides a forward estimate of rotation length and indicates that supplementation will be required or the paddocks should be taken for silage in periods of deficit or surplus feed respectively. The scale of supplementation or the number of paddocks is indicated. A herbage growth model (Brereton, 1987) which estimates growth as a function of radiation, temprature and soil water deficit is incorporated in the programme. The input to the programme includes the basic weather data and the date of last grazing of each paddock in the system. The forward estimate of rotation length is based on forward estimates of herbage available on each paddock. The forward estimate of herbage is based on a seven-day weather forecast and then on normal growth (long-term average). The expectation of normal growth following the period of the 7-day forecast may be varied optionally.

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WEATHER, ANIMAL DISEASE AND MODELLING

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Abstract

The relationship between animal disease and weather is examined and the reasons for attempting to model these relationships are discussed.The biological responses to weather are discussed in terms of both direct and indirect weather effects. Examples of both direct (e.g. cold stress) and indirect effects (e.g. development effects of extra-mammalian stages of parasites) are given. A number of different models in practical use are described. The first is the foot and mouth model which predicts the distribution of virus particles from a given source within a radius of 10 km using standard meteorological data.The next model described is the Ollerenshaw liver fluke forecast model - the first widely used disease forecasting model. Other working models for forecasting the incidence of nematodiriasis and parasitic gastro-enteritis are also discussed. These models of parasitic disease are essentially empiric in concept and are basically qualitative in their output. A number of experimental models based on mathematical analysis are also described in some detail - in particular the "Development Fraction" concept is explained. Models of this type are complex and often use simulation techniques, network theory or matrix theory in their formulation. They have not been developed beyond the experimental stage so far. It is pointed out that these models have a research and explanatory use in addition to a possible advisory use. Finally, the possibility of developing these models for practical use and incorporating them into decision-analysis models - the so called "expert systems" - is considered.

Introduction

Weather can have a profound effect on animal health in a variety of ways. First, there are the direct effects of weather on the production performance of livestock. These are not the subject of the present paper which is concerned with animal disease and more specifically with those diseases which have been associated with particular weather variables. A number of reviews have been published outlining the pathological conditions with which specific weather parameters have been associated or indeed correlated (O'Brien *et al.,* (in press); Grainger *et al.,*1986); O'Brien,1984; Starr,1981; Webster,1981; Ollerenshaw and Smith,1969; Thomas,1974; Smith and Thomas,1972. In many cases where the relationship can be demonstrated by sophisticated statistical techniques there may not always be a usable relationship for predictive purposes. For example the work of Martin *et al.*(1975) has clearly related seasonal weather variables with calf mortality retrospectively but this relationship might not transfer to a forecasting mode.

There are however a number of diseases which have been associated with specific weather conditions which can be quantified and which can be used for forecasting disease incidence sufficiently far in advance to be of practical use. The seminal example of this type of relationship was the fluke forecast model devised by Ollerenshaw and Rowlands(1959) which quantified the relationship in the form of an index - the M_t value. Alternatively, the relationship may be quantified as a specific prediction based on development or growth rate of infective organisms under conditions varying with time (Gettinby,1974;Nice and Wilson,1974;Connolly,1979).This paper is concerned mainly with relationships of a type which could provide a useful forecast for disease control purposes. There is moreover an aspect of such models which should not be forgotten - namely, that they can often help in understanding the dynamics of the disease transmission processes and are therefore useful in their own right.

Objectives of Modelling

There are at least two reasons for modelling a weather - disease relationship. The first is to provide a useful advisory tool to assist the farming community in minimizing disease losses by instituting control measures as early as possible. In this case, the model may be simple or complex but in either circumstance the approach is essentially pragmatic; that is the relationship between the chosen weather parameters and the measure of disease (incidence or prevalence) is not required to explain the biological reasons for the relation though in practice it may well do so. It simply accepts the correlation. Such models are usually only qualitative in their forecast.

The second reason for modelling may have a long term objective of providing a forecast as such or as a spin-off but generally it is more concerned with attempting to describe and/or explain the disease dynamics. Such a disease model may take various forms such as stochastic, simulatory or biological. It may be descriptive or explanatory or a combination of elements of both and may indeed even incorporate empirical elements. Models of this type are essentially computer oriented as they are frequently exercises in number crunching - particulary those that include simulation techniques. They also often incorporate the results of biological experiments, for example development rates, survival rates and fecundity rates which have been established in the field or laboratory.

Whatever the reason for attempting to model a disease-weather relationship, it is important to ensure that the measure of disease incidence is reasonably well established. For example,in the case of Ollerenshaw and Rowland's M_t value, the index was correlated with both disease incidence as recorded in the regional veterinary laboratories and field studies of the vector and its infection rate. In short, there should be a continuous process of local validation of the forecast. Furthermore, it must be remembered that the model is a model - not gospel. Conversely, to quote Macdonald (1965): "If they(the assumptions of the model) are sound, the model can give a qualitative picture of transmission with the relative significance of different factors, and of the modification of these factors even though their quantitative values may not be known." This is particulary pertinent in the case of the complex analytical/explanatory models.

Biological Responses to Weather

Animal health may be influenced by weather either directly or indirectly. These responses may be divided into a number of groups though there is considerable overlap as effects may influence different aspects of the disease condition.

1) Direct Weather Effects

Direct effects such as heat or cold are important in their own right; sunlight may be directly involved or associated with sensitizing agents in photo-sensitization conditions. There is the direct effect of weather on the animal which may be physiological such as simple heat or cold stress. More commonly, disease conditions are multi-factorial and weather factors may provide the trigger which results in the appearance of the clinical condition. The effects of these weather factors may be demonstrated by metabolic disturbances in that , with other factors such as malnutrition, they precipitate conditions such as swayback(copper defiency in lambs), hypomagnesaemia, hypocalcaemia and other diseases.

There is also the situation where weather conditions provide a stress in association with other factors (such as reduced immune response) which may act as a trigger in the disease process, for example in pasteurella pneumonia, though this may be a consequence of weather **change** rather than any particular type of weather(Webster,1981). These factors may also influence the incidence of other contagious diseases. However, it is difficult to demonstrate a useful predictive weather element in such conditions - the relationships tend to be retrospective.

2) Indirect Effects

Weather factors may contribute indirectly to infectious, contagious disease in a number of ways. In terms of modelling the classical example of mechanical transmission of disease spread as a function of weather is that of Foot and Mouth disease (Smith and Hugh-Jones, 1969; Gloster *et al.*,1981). There is also the effect of weather resulting in environmental conditions which are particularly suitable for the survival of infective, contagious agents. This is particularly important with pneumonic conditions caused by viral and bacterial agents(MacVean *et al.*,1986; Webster,1981).

A particular area where weather has obvious important effects is that involved in parasitic diseases. This is because many parasites have an extra-mammalian stage in their life cycle during which they are directly exposed to the effects of weather. Furthermore, it has been possible to experimentally measure factors such as growth or development rates in relation to time and temperature both in the laboratory and the field, thus providing the basis for establishing development patterns for use in mathematical simulation studies.

Models

a) Foot and Mouth Disease

An important and practical disease model which directly involves weather parameters in the transmission of disease is the Foot and Mouth model devised by Gloster *et al.*(1981). The model depends on the virus plume dispersion (based on the Gaussian dispersion equation), the concentration of the viral particles within the plume, the viral survival time and the down wind topography. The parameters input to the model are therefore an estimate of the daily virus output from the infected animals, hourly and three hourly observations of wind speed, wind direction, relative humidity,cloud cover and rain, latitude and topography.

$$C_{xy} = \frac{Q}{\pi U_{10}\delta_y\delta_z} . \quad \exp \frac{-y^2}{2\delta_z{}^2} \qquad (1)$$

(After Gloster *et a*l.,1981)

where Q is the strength of the virus source, U_{10} is the 10 m wind, z the vertical distance, δ_y and δ_z are dispersion coefficients and C_{xy} is the area location concentration. The output from the model is in the form of a calculated estimate of the dose of viral particles which a cow would inhale over a 24 hour period. This estimate is made for 360 locations within a radius of 10 km from the source. This model was validated against past outbreaks and was proved effective. It was also used with success by Donaldson *et al.*(1982).

This is a good example of a physical model which has been used in association with weather data to establish the dispersion pattern of the free virus particles. The approximations within it, such as the estimate of viral output, is of no great concern as this can be tested with a number of estimates. In the event the forecast output is relative and should be taken more as a probability estimate of infection potential at each calculated point.

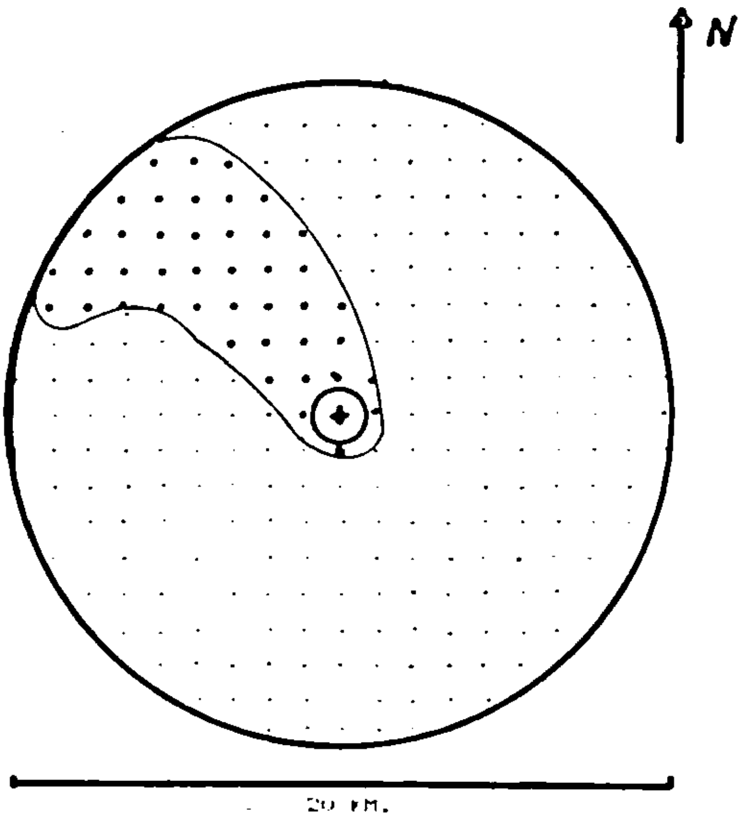

Fig.1. A diagramatic representation of the output from the foot and mouth model

b)Liver fluke disease

As already mentioned, the original model devised by Ollerenshaw *et al.* (1959) was the first example of a widely used and practical model for advising farmers on the expected risk of fascioliasis. It stimulated extensive interest in models for forecasting disease incidence, both empiric and analytical. As other fluke models will be discussed it is useful to give a brief description of the life cycle of the liver fluke, *Fasciola hepatica,* at this point.

The adult fluke lives in the bile ducts of many mammals, cattle and sheep being the most important. It is hermaphroditic and produces many thousands of eggs per day which are passed into the intestine with the bile and from there to outside with the faeces. Once outside the animal, the egg will proceed to develop providing that it has become separated from the faecal mass, that the temperature is above 10 °C and that there is adequate moisture. After a period of time, dependent on the ambient temperature, the egg will hatch in the presence of a water film to a miracidium. The *miracidium* will then seek out a mud snail (*Lymnaea truncatula*) into which it will penetrate and develop through an asexual stage of multiplication. On completion of this stage, which is again temperature dependent, the parasites become *cercariae* which will leave the snail in the presence of adequate water and encyst on herbage as *metacercariae.* In turn the herbage is eaten by cattle or sheep, within which the fluke will migrate from the intestine through the peritoneal cavity and then through the liver substance to finally arrive in the bile ducts where it becomes adult and once again starts laying eggs.

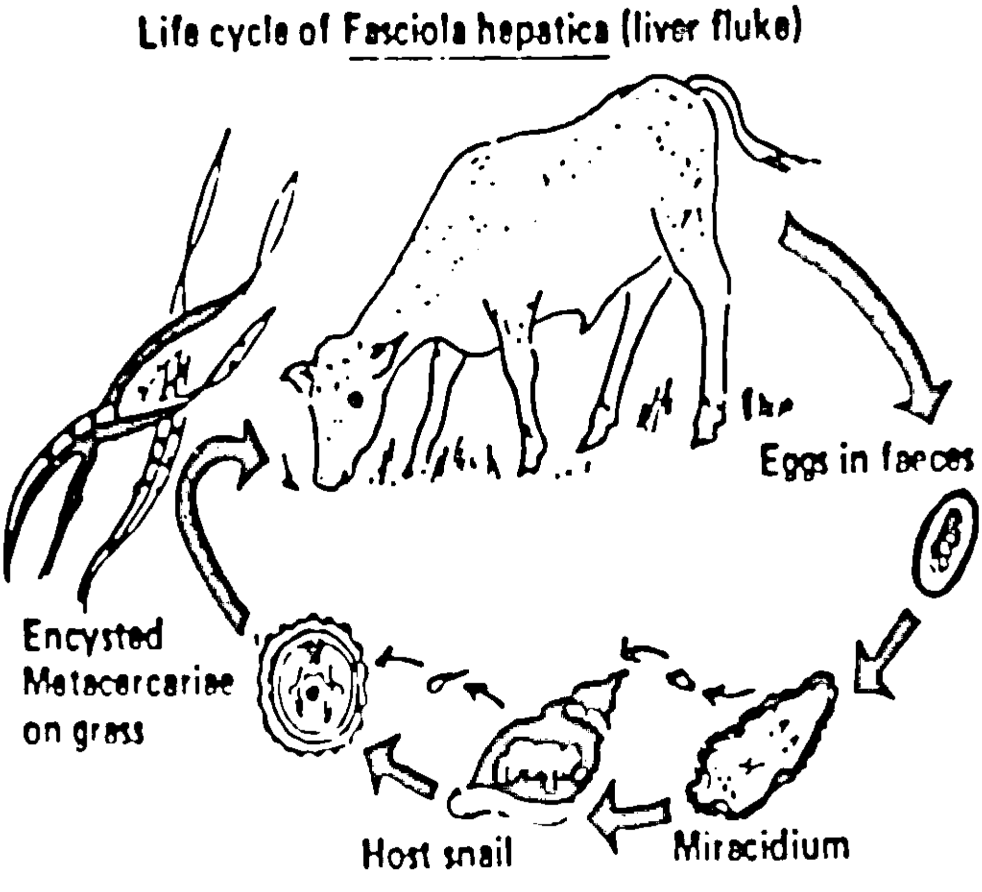

Fig.2. Life cycle of *Fasciola hepatica* (liver fluke)

The period from egg to *metacercaria* takes a number of weeks to complete during which it, or its host the snail, is exposed to the vagaries of the weather. Its development is therefore very strongly influenced by weather, particularly moisture and temperature. Temperature in practice determines the rate of development while moisture has a major influence on survival. Ollerenshaw has assumed that, on average, the temperature will not vary substantially from year to year and can therefore be disregarded. His model concentrates on estimating the "wetness" of the year and relates this to expected levels of infection.

The model is based on the monthly rainfall (R), the number of rain days (N), the evapotanspiration (P) and a constant which ensures that the result is always positive. The monthly estimate of the index, designated 'M' is as follows:

$$M_i = N_i((R_i - P_i) + 125))/25 \qquad \text{(maximum value} \quad 100) \tag{2}$$

$$M_t = \sum_{may}^{oct} M_i = 0.5\Sigma\,(M_{may} + M_{oct}) + \sum_{jun}^{sep} M_i \tag{3}$$

(The Ollerenshaw Index ; Ollerenshaw *et al.*,1979)

The sum of the 'M's from June to September plus half the sum of the 'M's for May and October is the final index value for the infection developing over the summer. A modified version is defined for over-wintering infections. Despite its simplicity, this model has been proved to be very effective over a wide area of Europe, modifications being made in a number of countries (Ollerenshaw, 1973a; Leimbacher,1978).

Another even simpler model was developed by Ross (1970). This was based on the number of wet days (i.e.a wet day is one on which 1 mm or more of rain falls in the 24 hour period). It is a progressive forecast in that it is based on the accumulated number of wet days at various times throughout the year. This allowed a provisional forecast to be made at the end of June and to update this in mid-July, the end of August and the end of September. Again , this model like the Ollerenshaw model takes no account of development rates. It has proved useful in both N. Ireland and Scotland (Ross and Woodley,1968; Ross, 1978).

A combination of monthly total rainfall and raindays has been used satisfactorily for forecasting the incidence of liver fluke disease in the Netherlands (Ollerenshaw, 1973b). In this case a divergence of the observed rainfall for each summer month from the long term mean for that month is recorded either as 1, 0.5 or 0 according to whether the observation is above, equal to or below the average. A similar assessment is made for raindays. These two values are summated for each month during the summer, thus providing a continuous update. A sum of 3 by the end of June or 4 by the end of July indicates a high incidence of disease.

As noted above, these models do not incorporate any estimate of temperature effect. Grainger (1959) had demonstrated that the development time for frogs' eggs under varying temperature conditions could be predicted reasonably well by using growth rates determined in constant temperature experiments. Gettinby (1974) followed this up and evolved the concept of the "Development Fraction". This consists of establishing the relationship between temperature and time(D) to complete development of a particular stage of the parasite. It is then assumed that after unit time at this temperature, the development fraction is:-

$$1/D_T \tag{4}$$

where T is the temperature at which the development occurred. It is further assumed that under varying temperature conditions when the sum of the individual development fractions for each time unit is equal to or greater than one, the development of the between the observed and calculated times to completion may not be important in a practical forecasting situation. The actual model is shown below.

$$D_T = 1/(B_0 + B_1T + B_2T^2 + B_3T^3) \qquad (5)$$

and

$$\sum_{i=o}^{n} 1/D_i \geqslant 1$$

(the development fraction:Gettinby,1974;Connolly,1987)

where the B's are regression constants.

Gettinby (1974), using biological data obtained from studies on the liver fluke development models based on these ideas for both the development of the fluke egg and of the intra-molluscan stages. These can be combined in an algorithm using weather data together with certain basic parameters, such as stock numbers and percentage of the farm which is habitat, to predict the cercarial shedding time; this assumes that moisture is not limiting (Gettinby *et al.*,1974). Using snail growth data a somewhat similar model was described by Nice and Wilson (1974)and by Williamson and Wilson(1978). However, both these models do not take into account the effect of moisture.

While temperature determines the basic rate of development, moisture has a restrictive effect. Its absence can stop development and additionally has a marked effect on survival. Thus the temperature model on its own is of limited value. Hope Cawdery *et al.*(1978) did some preliminary work to incorporate a moisture element to the basic temperature model. This suggested that there was potential for this type of model as the figure below shows.

Figure 3 shows the relationship between the observed accumulation of fluke pick-up in tracer sheep and the predicted accumulation from the model.

Another useful model to incorporate in a forecasting system relates to survival (Gettinby,1974). Essentially, it is based on survival at constant temperature such that:-

$$S_T = \exp(-\beta_T N_T) \qquad (6)$$

S_T is the observed completion rate of the stage (e.g hatching rate of eggs) and is an exponential function of the survival rate (β_T) and the number of days (N_T)at that temperature. Under conditions of varying temperature, the overall survival rate of the stage is given by:-

$$S_n = \pi_{i=0}^{n} \exp(-\beta_{T_i}) \qquad (7)$$

(survival prediction; Gettinby,1974)

where S_n is the continuing product and n is the number of days to complete development of the stage. T_i is the temperature on the ith day and β is the survival constant.

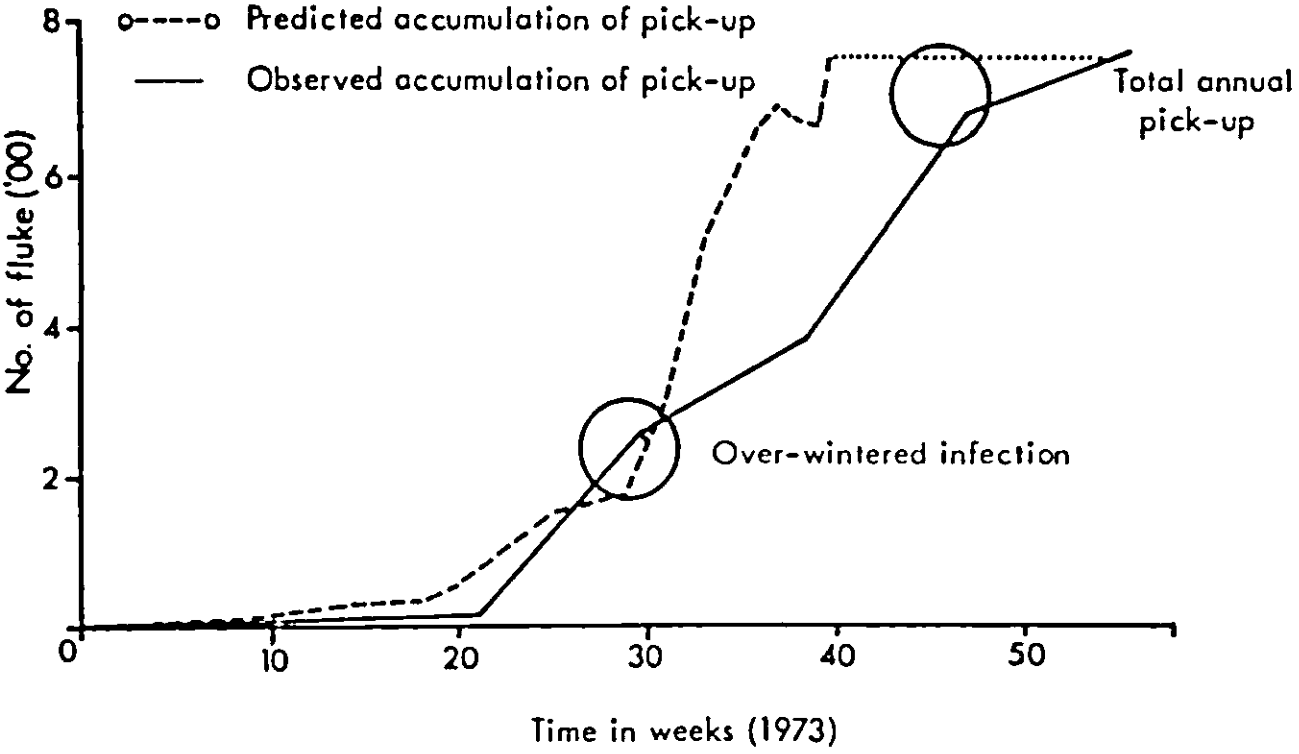

Fig.3. The average observed (——) and predicted (- - - -) accumulation of fluke in tracer lambs

c)Nematodes

These parasites all have a direct life cycle, that is there is no extra-mammalian host and no multiplication of the parasite in the environment. They are, however, subject to the effects of weather. Temperature determines the rate of development from the egg to infective larva in most cases. Moisture influences survival, activity and transmission.

i) Nematodiriasis

This is a disease of sheep and cattle caused by worms of the genus Nematodirus. It is particulary important in sheep and *N.battus* (the most epidemiologically typical and possibly most pathogenic species) can cause serious losses in lambs, adult sheep being immune to infection. A number of authors (Thomas, 1959; Gibson,1963; and others) have noted that the incidence of the disease was most severe after a cold winter and a late spring. It was found that this relationship was due to the hatching mechanism of the parasites' eggs. In short, under cold conditions the hatching of eggs is delayed and is followed by a sudden appearance on herbage of big numbers of infective larvae. This factor together with the presence of older, grazing lambs results in high infection levels.

Ollerenshaw and Smith (1966) made use of these observations to suggest an empirical solution to forecasting disease incidence. The model devised by them was based on 30 cm soil temperature at Oxford and Newcastle. The equation is given as follows:-

$$I_3 = 52.5 - T_0 - T_{cp}/10 \quad (8)$$

where I_3 is the Index, T_0 and T_{cp} are the mean March soil temperatures (30 cm depth) at Oxford and Cockle Park, Newcastle respectively. The value of I_3 is given below:

Disease	I_3	Soil Temp(°C)
High incidence	$I_3 > 8$	< 4.7
Above average	$5 < I_3 < 8$	4.7 - 5.8
Below average	$3 < I_3 < 5$	5.8 - 6.9
Low incidence	$I_3 < 3$	> 6.9

(Ollerenshaw and Smith,1966)

Alternatively, the mean March soil temperature (°C) at 30 cm depth can be used as above as an index of disease risk. Further work on this problem has resulted in a model which forecasts the hatching date of the parasite(Smith and Thomas, 1972). The index is given below:-

$$I_h = 54.0 - 7.2\,T_{20} \quad (9)$$

(after Smith and Thomas,1972)

where I_h is the number of days after 31st.March to peak hatch and T_{20} is the mean 30 cm temperature (°C) for the period 1-20th. March. This model provides information on both the likely intensity of infection and its timing. Hence, it provides a useful basis for advising on the appropriate control measures.

ii) Ostertagiasis

The main cause of bovine parasitic gastro-enteritis in Britain and Ireland is *Ostertagia* spp., while *Trichostrongylus* spp. and *Cooperia* spp. are usually less important. Following the success of forecasting techniques in predicting the incidence of the parasitic diseases mentioned above, there has been a considerable amount of work directed to providing a suitable system for bovine parasitic gastro-enteritis. As the major problem is caused by *Ostertagia* spp. the majority of the work has been done on this parasite. Both methods *viz.* the empiric and the analytical, have been used in formulating models to forecast disease incidence. The former method is typified by the work of Ollerenshaw and Smith(1969). They have established, for cattle, a relationship between the incidence of early summer infection (I1) and the mean rainfall (R)(in inches) for the period August to October of the previous year and the observed disease rating (D) in that year. The relationship is:-

$$I_1 = 13 - R - 0.5D \quad (10)$$

The relationship for the late summer infection (I_2) is given as:-

$$I_2 = 8.0 - 1.7J + 0.6D_1 \tag{11}$$

(after Ollerenshaw and Smith,1969)

where J is the soil moisture deficit at the end of July and D_1 is the early summer disease rating. A similar approach has been used for parasitic gastro-enteritis in sheep (Ollerenshaw *et al.*,1978). This model, which involves the use of moisture parameters, is complemented by the work of Thomas and Starr (1978) which determines the timing of peak larval counts. It is not proposed to go further into the details of these models at the present time.

The analytical approach has been spear-headed by Gettinby and his associates in a series of papers (Gettinby *et al.*,1979; Gettinby and Paton, 1982; Gettinby and Gardiner, 1980) and by Paton and Gettinby(1983); Paton et *al.*,(1984); Young, Anderson *et al.*,(1980) and Young *et al.*, (1980). This work has been based on mathematical models which attempt to predict the times to completion of the stages of the parasite in the extra-mammalian habitat using experimental data on development rates.

Gettinby *et al.*(1979) used the development fraction concept as the basis of their model to which was incorporated parameters involved in infectivity, fecundity and survival of the free-living stages. Particulary, a sub-model to calculate the number of adults established on day i was included. The model is shown below:-

$$A_{i+1} = (110000 - A_i)(1 - e^{-0.00000255L}) + A_i \tag{12}$$

(The sub-model for predicting the number of adult Ostertagia established on the (i+1)th day; Gettinby *et al.*.,1979)

where A_i is the number of adults established on the ith day and L is the number of infective larvae ingested 21 days earlier.

This was validated against the observed pattern of pasture larval counts which it matched reasonably well. The model itself could be used to predict the development pattern of pasture larval counts. This, in turn, could provide useful information to advise farmers on the need to move, or to warn of the increasing risk of infection. Gettinby and Paton (1982) have also shown that the prediction may be influenced by strain differences of the parasite.

iii)Parasitic bronchitis - 'Hoose'

This disease is caused by *Dictyocaulus* spp. in both cattle and sheep . It is particularly important in cattle. Like the other nematodes its life cycle is direct but the development period is much shorter which is one factor making it difficult to predict pasture larval infections. It is also affected by weather conditions but the relationship is complex and the parasite (*D.viviparus*) is very unpredictable in its behaviour even on experimental pastures (Downey, pers. comm.). However, recent work (Somers *et al.*,1985)has shown that, in Ireland as elsewhere, the fungus *Pilobulus* spp. is involved in dispersing the larvae from the faecal mass and can be important in influencing levels of infection in calves. It was also shown that *Pilobulus* is weather dependent. It may be possible to use this relationship to predict pasture larval densities and/or high risk periods in terms of dispersal.

Arthropods

Ticks

The only tick of consequence in Ireland is *Ixodes ricinus*. It does, however transmit a number of serious diseases to farm livestock. The most important of these are louping-ill, tick-borne fever, tick pyaemia and bovine red water fever caused the protozoan *Babesia divergens*.

It has been known for a long time that weather influences ticks and their activity (MacLeod; 1936). Donnelly and MacKellar (1970) have further shown that there is a very significant correlation between disease incidence (transmitted by the tick) and maximum air temperature providing that the periods January to May and June to September are considered separately because of the basically bimodal activity pattern of ticks. They established equations for the "spring" and "autumn" disease patterns which were similar to observed patterns. However, these relationships appeared to be local in nature. A point raised by these authors was that the incidence for bovine redwater fever was offset by 14 days - the prepatent period of the disease. While the forecast would not allow prevention of disease it might well provide an early warning of existing infection.

Gardiner et al,(1981) developed a prediction system based on the development fraction concept noted above for liver fluke. Subsequently this procedure, together with information on activity, attachment and ovipositon, was incorporated into an overall model of the tick life-cycle to predict the level and timing of tick activity throughout the year. This included an analytical description of the daily output of eggs which is required for the basic population model. This model also attempted to incorporate survival rates and factors influencing biological diapause (Gardiner,1983; Gardiner and Gray,1986).

The life cycle of the tick is extremely complex and may be extended up to 6 years depending on factors such as hatching date, feeding time and diapause and the effect of weather on them. It is therefore of considerable importance to understand the biology and population dynamics - something to which these models have substantially contributed.

Discussion

The Foot and Mouth model, the Ollerenshaw Index and the Nematodirus models are all available and in use for forecasting the risk of infection for their respective diseases. While further development may be necessary, the benefits they can provide have been established. The other models described have yet to become available as portable programs. There is a problem in taking an experimental program and developing it for general use. It has to be "debugged", edited and annotated so that the user can understand the package. As the programs are generally complicated, this represents a considerable amount of work for which time may not be available by the originators of the work. This, then represents one problem of moving a forecast program from experimental to routine use. It is something which will have to be done if this work is to be of practical value.

A potential use of these programs would be to integrate them into a cost-benefit type of package whereby the optimal control package can be conceived, or an alternative, less effective but a more practical program, can be proposed. A more useful approach might possibly be to integrate these models with an expert system whereby the forecast can be combined with assessments by an expert user to provide the required control strategy. Basic expert systems (decision analysis models) are available as computer packages and their use in this context would appear to be a useful area for development.

Finally, it is clear that weather has a substantial and sometimes measurable or predictable effect on animal disease. However, until the incidence and prevalence of diseases is fully recorded on some form of database, it will be extremely difficult to fully assess these effects, to develop disease forecast models or to validate them. Consequently, it is particularly important that an efficient means of monitoring animal diseases in general is available for the full development of disease-weather models.

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TRENDS IN WEATHER FORECASTING

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Abstract

Computer based weather forecasting is discussed with emphasis on the quality of management information likely to become available from this source over the next few years. Development of satellite and radar technology is briefly described with indications for short-range forecasting. A description of presentation techniques is given with reference to the new weather presentation system developed with RTE.

Introduction

Up until quite recently, all weather forecasting was based on the synoptic method. This system involved collecting together on a map a series of weather observations made simultaneously in many different locations. The map was then "analysed", i.e. areas of high pressure and low pressure were identified, and the frontal systems—bands of cloud and rain—were marked in. A similar analysis of pressure, wind and temperature was carried out at 10,000, 20,000, and 30,000 feet altitude. The art of forecasting was concerned with examining these charts and, from this examination, preparing a chart which showed where the various weather systems would be 24 and 48 hour hence.

How did the forecaster know where these systems would be? To a certain degree, this derived from examination of which way the systems had moved during the previous 24 hours. Partly, it derived from an examination of the upper air winds. Partly, it was based on empirical rules. The largest element derived from the experience of the forecaster, coupled with an understanding of the physical processes that were taking place. But, of course, the laws governing the movement of the atmosphere are not empirical; they can be written down in rigorous form. Unfortunately, these laws take the form of complex differential equations that cannot be easily solved, and that certainly could not be used on a day-to-day basis by forecasters in the production of weather forecasts.

Computer generated forecast fields

The way in which computers produce weather forecast information differs fundamentally from the "human" approach. A grid of points is set up covering the surface of the earth. In the forecast model run by ECMWF (The European Centre for Medium-Range Weather Forecasts), the grid in current use has a spacing of approximately 1° . The grid extends vertically through 19 seperate levels; the lowest on the surface and the highest at a pressure of 10 hPa, approaching 30 km in altitude.

Observations taken at surface level are made available to the computer, as are observations taken in the upper air by balloon ascent; also wind and temperature information are received from aircraft. Additional information arrives at the computer from weather satellites; from this, the height and movement of clouds can be inferred.

When all the information has been put into the computer, it is interpolated to each of the grid points which are already set up, and for each of these grid-points the relevant values of pressure, temperature, wind strength, and other such parameters are assigned. The differential equations are then applied to this mass of data, and integrated forward in time to produce a new set of parameters. Obviously, there are errors inherent in this procedure, and the further ahead in time that is integrated, the more rapidly these errors accumulate. This imposes a limit to the usefulness of the forecasts (Figs.1 and 2).

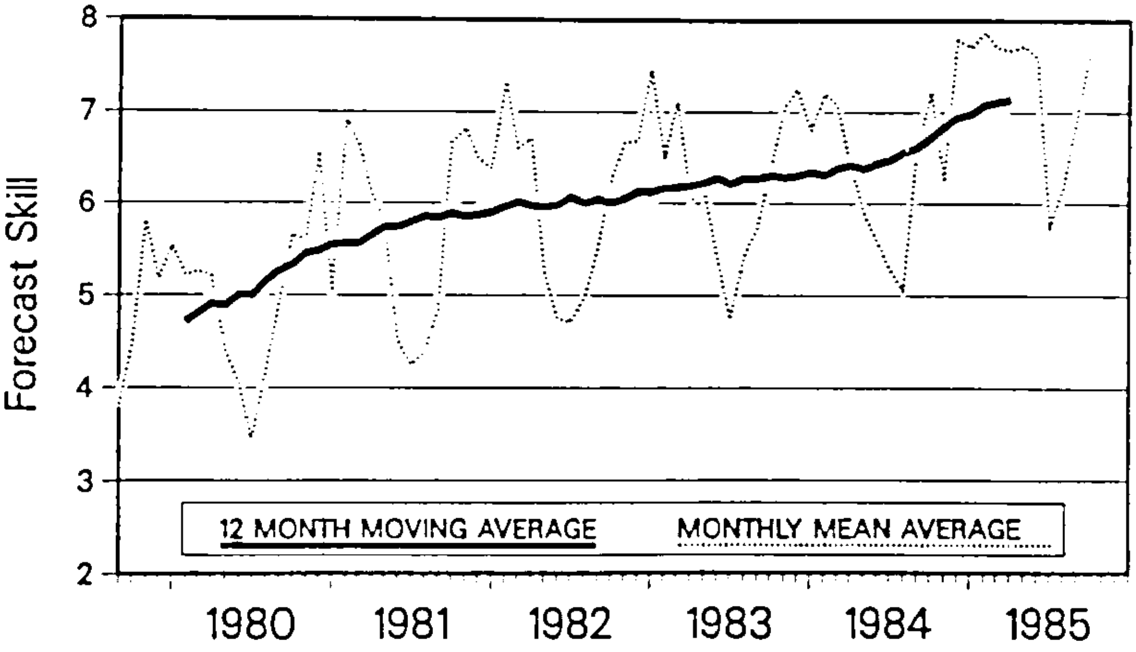

Fig.1. ECMWF forecast skill, September '79-September '85 (ECMWF *Newsletter* No 35, 1985)

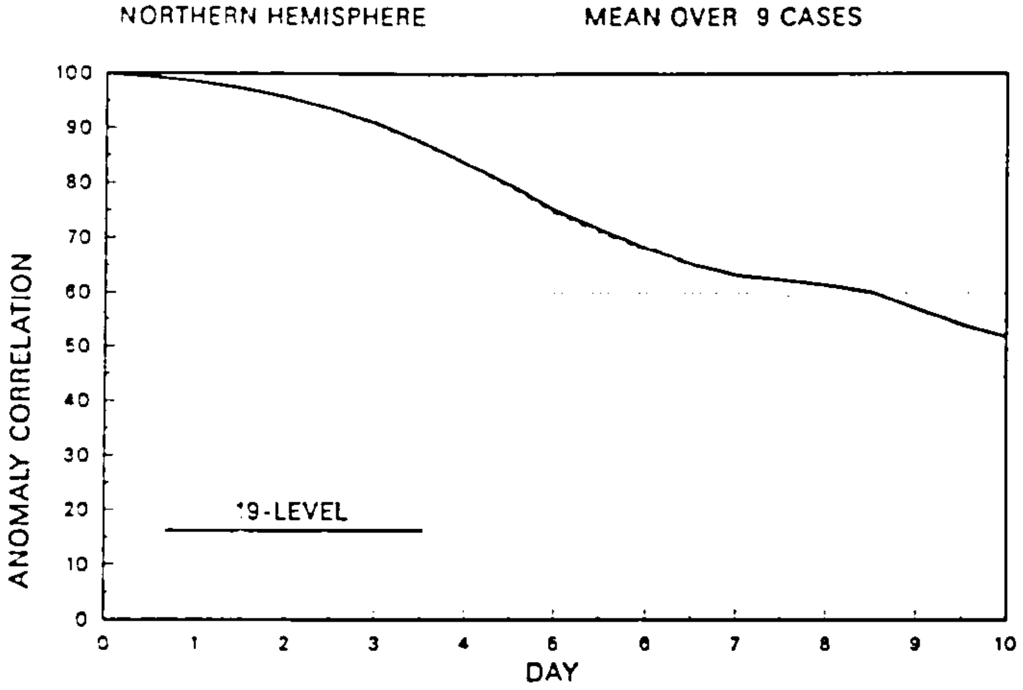

Fig.2. Changes in mean annomaly correlation (forecast *versus* (subsequen)t actual situation) through the 10-day forecast period (Wergen and Simmons, 1986).

Interpretation of the computer products

Once a set of data for a particular time has been generated, it has to be interpreted. People are not interested so much in pressure values, vorticity, or many of the other rather exotic parameters in which the computer deals—they want to know if it will be wet, sunny, windy, or warm! The interpretation procedures which bring the parameters (the computer deals in) back to something that we can all relate to, are one of the most difficult elements of the whole calculation (Bottger and Persson, 1988).

The main point about computer-produced forecasts is that the output is expressed numerically. The computer can be asked questions like—how much rain will there be tomorrow? What will the temperature be at noon? What will the wind be at 1800 hrs? The computer will reply with a number. This is excellent for those who need numbers to "plug into" models,— grass and sugar beet growth models, potato blight models, and so on. But the danger with such numbers is the tendency to accept them as fact without questioning the inherent errors and the limitations of use that follow from the way in which the numbers have been obtained (Narmi, 1985).

Consider the grid points for the ECMWF forecast model overlain on a map of Ireland(Fig.3). It can be seen that in reality the model only attempts to provide information concerning eight discrete points overland. Information for any other point would have to be interpolated. Indeed, if information is desired for a point directly coincident with a grid-point, the preferred option for deriving that information is to take a statistically weighted average of the values at the grid-point and at surrounding points.

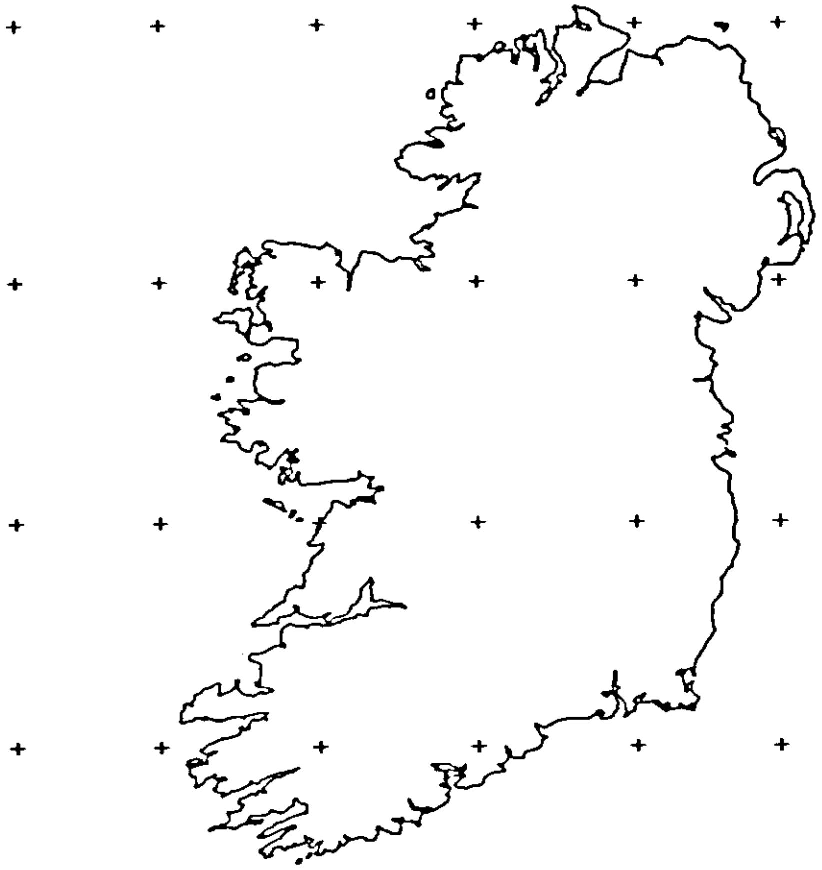

Fig.3. Computer grid-points in the EMCWF forecast model in the vicinity of Ireland.

Further complications arise in relation to the inbuilt topography of the ECMWF forecast model (Fig 4). This is necessarily very coarse and the representation of Ireland is extremely crude. In general, the model can only properly represent large-scale features, extending over many grid-points. It is not good at representing features at a point in any meaningful way. But this "weather at a point" is exactly what most people are interested in.

All this is not to say that computer models cannot be used to forecast fine detail. Developments in the next ten years will concentrate very much on models covering just a small area of the globe, but covering this area with grid-points in a fairly dense fashion. The historical problem with this approach was that the smaller the area covered by the model, the shorter was the range of the forecast obtainable—given the rate of movement of weather systems across the small area. This can be solved by taking the boundary conditions for the limited area model from the large, global models, but using the limited area model to put detail on the area in question. The British Meteorological Office runs a "fine mesh" model which produces forecasts out to 36 hours. The Irish Meteorological Service has its own limited area model; this uses ECMWF forecasts to determine the boundary conditions. These fine mesh models are not good for 4/5 day forecasts; such forecasts would derive from boundary conditions produced as 3/4 day forecasts by the global models, thus imposing a basic limitation on the accuracy of the end product.

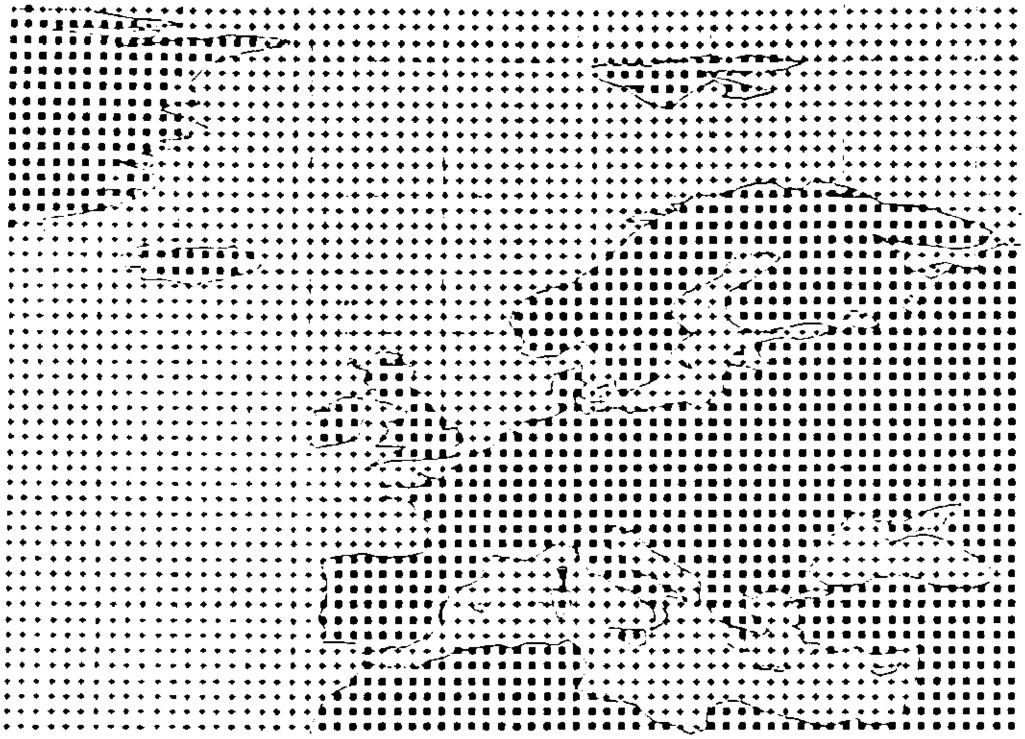

Fig.4. The land-sea mask by which each gridpoint is defined, as to whether its surrounding is more or less than 50 per cent land (or sea). Note that islands like Crete, Cyprus and the Danish islands are not large enough to be included (Bottger and Persson, 1986).

The Future

Increasingly fine-mesh models will be seen running "piggy-back" with global models and providing the resolution to more accurately predict spatial variations in rain, cloud and wind. It is likely that these will develop as integral with the global models. A centre such as ECMWF would run its global model and its fine mesh model simultaneously, with a continuous flow of information back and forth between the two. This technique is known as "nesting" (Smagorinsky, 1985).

Parallel to this would be the development of Model Output Statistics (MOS) techniques to improve the ability to predict point processes. These techniques compare computer derived forecasts for a point with the actual weather that occurred, and seek thus to identify the systematic errors inherent in the computer treatment. Knowledge of the systematic error can then be used to "correct" future forecasts.

It is vital that meteorologists working with these techniques, and researchers developing weather-dependent models of their own, collaborate much more closely, so that optimum use is made of the entire forecast system. The process of adjusting weather dependent models to lean on the strengths, and avoid the weaknesses, of the forecast models still has a long way to go.

The models have been described in some detail here, to give some indication of the way that they work, and to help promote an understanding that they cannot be seen merely as "black boxes", churning out numbers.

Very short range forecasts

Short range forecasting (less than 6 hours ahead) is based primarily on the use of satellites and radar. In the former case, Europe is well served with the geostationary satellite (METEOSAT) and the American polar-orbiting satellites (NOAA). What is lacking in this country is the equipment to make the best use of the data that these satellites generate. All of the Meteorological Service's satellite receivers are of the low resolution type, adequate for producing a visual image but not good enough to allow accurate quantitative interprepation of, for example, cloud-top temperature. High resolution equipment does exist; in the case of NOAA it is a question of better receivers, in the case of METEOSAT it would mean the reception of high-quality data via a land link to Darmstadt in Germany, the headquarters of the European Space Operations Centre. The problem here is the cost—these facilities could cost about £0.25m per year.

The other forecasting tool of use for this timescale is radar. Radar can show exactly where rain is occurring now; its intensity and extent. A sequence of radar images taken, say, every 15 minutes allows one to estimate the rate of movement of the rain. Over a time interval of 3 or 4 hours a rainbelt will not change appreciably in intensity although it may move a considerable distance. Its extent, intensity and movements can be estimated, and an accurate forecast for any given location in regard to the rain, for up to 4 hours ahead, can be made. The Meteorological Service operates two weather radars; an old type model based at Dublin Airport and a more up-to-date machine based at Shannon Airport.

The output of the Shannon Airport radar is available in the Central Analysis and Forecast Office in Glasnevin. With a range of 130 to 160 km this radar gives coverage over Munster, much of Connaught and parts of Leinster. The British Meteorological Office has recently installed a weather radar near Lough Neagh, and the output from this will also be fed to Glasnevin in the near future. Between them, these two radars will give reasonable coverage over half to two-thirds of the land mass of Ireland, but for full coverage both of the land and the surrounding seas, two further radars would ideally be needed, located respectively in the northwest and the southeast. The problem, again, is money—each radar would cost something of the order of £0.5m, with a lifetime of fifteen to twenty years. For fully quantitative use of a system of weather radars, a parallel system of rain gauges should be installed, connected to a central computer and capable of interrogation in real time. These would be used to provide a continuous "calibration" of the echo signal derived from the radars, so that the indicated intensities would be meaningful.

The sort of information being discussed has a very short "shelf life". To be fully useful it must be delivered to the end-user very quickly— say, within half an hour. The only reliable way to do this would be with some kind of videotex system whereby the user could view, on his or her own television, a sequence of 8 or 9 radar images taken at 15 minute intervals. Ideally, the users would be able to mark their own locations with an "x"; this would aid them in assessing whether rain areas or showers would be likely to affect them. The implications of this level of information for operations such as crop-spraying would be substantial—with a full network of radars the system could, in certain instances, provide useful information for up to 6 to 8 hours ahead. The information would be of optimum use when taken in conjunction with the usual forecasts available on radio, television, and over the phone.

Television presentation of weather information

Recently, a new system for the presentation of weather forecasts has been introduced on RTE television. The new system represents a significant improvement in the business of transmitting weather information. It is a major step away from the old fixed format forecast so familiar to viewers.

The new presentation system revolves around computer produced graphic images prepared directly by the forecaster—the main attribute of the system is its flexibility. Background maps of the Atlantic, Europe or Ireland can be chosen, and superimposed on these may be isobars, systems of fronts, winds, temperatures, weather symbols, key words for summary—charts can be set in whatever order desired. For the first time, full use of the medium of television is made; information is presented in visual form so that the viewer receives the story by eye and by ear. This is an important difference.

Heretofore, meteorology has tended to identify with the specialist user— airline pilots, ships captains, and so on. Recently, it is realised more and more the benefits of having accurate forecasts understood and acted upon by the ordinary citizen in his or her daily business. Within the country there are a number of interest groups—farmers and builders are particular examples —for whom accurate weather forecasts have special economic implications, but who generally get their information from the mass media—radio, television, and the newspapers (see Shields, 1987). Presentation techniques, therefore, have to be seen as an integral part of meteorologists' work as scientists, because the work is wasted if information is not delivered to the end user in time for useful decisions to be made.

Isobars are contour maps of pressure. The new presentation system has been specifically designed for the preparation of contour maps, but not solely of pressure. Using the system, charts showing, for example, accumulated rainfall, total hours of sunshine, perhaps effective blight hours or even degree-days can easily be incorporated. Forecasts for six hours ahead, or for four to five days ahead can be presented. The information is available, the presentation techniques are available—all that is needed is preparation time and a slot in the broadcast schedules. What should be aimed at over the next 5 years is to build on the close liaison that already exists between the Meteorological Service and the various agricultural bodies, so that explicit detailed and specialised information appropriate to farming problems at particular times of the year can be efficiently collected and properly presented.

Videotex and phone forecast services

There are two other means of forecast dissemination that will play a key role in the years to come. Videotex, or teletext have already been mentioned—there are two services of this type currently, the Agriline service operated by ACOT and AFT, and the Aertel service, run by RTE. The possibility of incorporating sequences of radar images as pages of videotex information has already been mentioned, the possibility also exists of sequences of satellite images. It would be desirable to see a trend towards regional forecasts, tailored to an area of perhaps a county or two in size, and frequently updated. Parallel to this videotex service would be the Automatic Telephone Weather Service (ATWS).

A new ATWS for the North-West Region—North Connaught and County Donegal has recently been commenced, and this means that now all parts of the country have access to this service. However, many of the regions on this system are still too big, e.g. one forecast covers the whole of Leinster plus counties Cavan and Monaghan. Regions need to be divided into two or three smaller areas that, climatologically speaking, would be likely to experience similar weather. Such a local service would likely command much greater confidence among users. It is desirable to design the system so that all callers to an ATWS would pay for the call at a standard rate. At present, taking the Leinster forecast again as an example, callers living close to Dublin pay the tariff of a local call—others pay up to 36p a minute. It would be more equitable to charge all callers at a fixed rate, and if this was set at, for example, 20 or 25p, there should be no loss in overall revenue.

Forecasting the future always involves a degree of uncertainty, and those of us who do it for a living are unlikely to suffer from over-confidence—the vargaries of the Irish climate are sufficient to assure that. How much more speculative, therefore, is forecasting the future of forecasting itself? Before we take ourselves too seriously, it is well to remind ourselves of three predictions made by the eminent 19th century physicist, Lord Kelvin. In 1895, he declared that heavier-than-air flying machines were impossible. Two years later, he said that radio had no future, and in 1900, he denounced X-Rays as a hoax! If our predictions last as long they will probably look equally foolish. Ten years is a long time in meteorology.

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Appendix *I*

Scientific Exhibition

Automatic Weather Recording

Organization	In Attendance
Bórd na Móna, Newbridge, Co Kildare	J. Dolan; M. McNulty
Campbell Scientific Ltd, Sutton Bonington, Loughborough,Leistershire LE12 5RA, England	R. Saffell
Didcot Instrument Company Ltd, Thames View Industrial Estate, Abingdon, Oxon OX14 3LD, England	P. E. Izzard
Meteorological Service, Dublin	B. Noonan

Computer Models

Organization	In Attendance
Johnstown Castle Research Centre, AFT Herbage Growth Model and Grazing Management System.	A.J. Brereton; O.T. Carton
Oak Park Research Centre, AFT Computer Models on Winter Wheat and Potato Growth and Development.	J.I. Burke; J. Gibbons
ACOT/AFT Agriline Videotex Service	G.McCann; Q. Scally
Department of Agricultural Civil Engineering, UCD Evaporation Modelling	S.M. Ward; V. Kuhnel
Meteorological Service Weather Maps; Foot and Mouth Disease Dispersal Programme.	G. Fleming; D. Fallon

Poster Session

Organization	In Attendance
Bórd na Móna, Newbridge, Co. Kildare Weather Relationships with Peat Production.	J. Dolan ; M. McNulty,
Department of Plant Pathology,UCD/ **Department of Plant Science,UCC** Influence of Climatic Factors on Conidial Dispersal Patterns in *Drechslera teres* in spring Barley Field Plots.	B.M. Cooke; M.L.Deadman
Forestry Services(Dept. of Energy) Effects of Wind on Tree Growth and Tree Stability; Effects of Weather on Seed Production and Forest Fires; Effects of Shelter on Wind-Run.	J.O'Driscoll; E. Hendrick; A. Pfeifer

Appendix II

AGMET Publications

First Report	March 1985
The AGMET Index: *Irish Scientists Concerned with Agricultural Meteorology*	March 1986
Weather and Agriculture (booklet in association with Agricultural Credit Corporation plc (ACC))	October 1986
Climate, Weather and Irish Agriculture(*Gen Ed; T. Keane*) (textbook sponsored by ACC; available from Agricultural Trust,Irish Farm Centre, Bluebell, Dublin 12. Price £9.95)	October 1986
Automatic Climatological Recording: *Report prepared by AGMET Subgroup on Automatic Weather Recording (Chairman ; W. Burke)*	October 1987
Proceedings of Conference on Weather and Agriculture	June 1988