THE DEFINITION OF AGROMETEOROLOGICAL INFORMATION
REQUIRED FOR PASTURE AND LIVESTOCK PRODUCTION IN
TEMPERATE REGIONS

by

(A.J. Brereton and C.J. Korte)

WMO/TD-No. 809
Geneva, Switzerland
April, 1997
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PREFACE

The 10th meeting of the Commission for Agricultural Meteorology of the World Meteorological Organisation took place in Florence, Italy in 1991. The Commission there passed the following resolution:

Res. 14 CAgM-X : Rapporteurs on the definition of agrometeorological information required for pasture and livestock production

The Commission for Agricultural Meteorology
Noting:

1) The recommendation of the Advisory Working Group of the Commission on the establishment of working groups and appointment of rapporteurs,
2) The report of the rapporteurs on Agrometeorology of Grass and Grasslands for Middle Latitude regions, and
3) The report of the rapporteur on Agrometeorology of Grass and Grasslands in tropical and Sub-tropical regions,

Considering:

that there is a need to define agrometeorological information required for livestock production,

Recognizing:

the social, economic and environmental importance of the application of agrometeorological knowledge and information to planning and operational activities in pasture and livestock production,

Decides

1) To appoint rapporteurs on the Definition of Agrometeorological Information Required for Pasture and Livestock Production for

   a) Temperate climatic regions,
   b) Cold climatic regions,
   c) Tropical and Sub-tropical humid and sub-humid climatic regions, and
   d) Arid and Semi-arid climatic regions,

with the following terms of reference

i) to describe in quantitative terms agrometeorological information required by the users for both planning and operational management of pasture and livestock production;
ii) to formulate such information for different stages of pasture and livestock production including storage and transport operations in a readily usable, user-oriented form;
iii) to provide examples from Member countries of the use of such information;
iv) to summarise in detail social, economic and environmental benefits of such information;

v) to identify potential contributions to CARS-food;

vi) to submit annually information on progress of activities and a final report to the co-coordinator;

2. To invite the following experts to act jointly as rapporteurs; an expert form New Zealand and an expert from Ireland for temperate regions; Dr. S.A. Danielow (USSR) for cold climatic regions; an expert from India and an expert from Indonesia for tropical and sub-tropical, humid and sub-humid climatic regions; Dr. Xu Deyuan (China) and an expert from Brazil for arid and semi-arid climatic regions.

3. To invite the expert to be nominated from New Zealand, the expert to be nominated from Indonesia and Dr. Xu Deyuan (China);

   a) to act as co-coordinators for temperate, for tropical and sub-tropical and for arid and semi-arid climatic regions, respectively;

   b) to submit annually information on progress of activities and a final report to the President of the CAgM not later than six months before the next session of CAgM.

Subsequently, Dr. Chris J. Korte of New Zealand accepted the invitation to act as co-coordinator and rapporteur for the temperate climatic regions and Dr. A.J. Brereton of Ireland agreed to assist him. As the result of re-structuring in the research organisations in which they work it has not been possible to adhere fully to the terms of reference given in the above resolution. This is regretted but it is hoped that the present report nonetheless serves to advance the objectives underlying the resolution.

Much of the information presented in this report on the range of agrometeorological services provided to the livestock producer in relation to the size of the livestock industry and its social significance was based upon the responses received from thirty countries to a questionnaire. This report does not present these responses, but the reader can contact the WMO Secretariat if a copy of these responses is required.
ACKNOWLEDGEMENTS

We are grateful to various individuals whose generous assistance made the writing of the Report possible. Chapters 1, 3, 4 and 9 are based on work by Dr. Aidan Conway (Teagasc), Dr. Padraig O'Kiely (Teagasc), Mr. Brendan Lynch (Teagasc) and Dr. Pat Dillon (Teagasc). The international survey was only made possible by the efforts of the WMO Geneva Staff and by the officers of the many National Meteorological Services.

Ms. Margaret Egan (Teagasc) typed the Report, and but for her generous efforts, the Report would be even more delayed than it is.
INTRODUCTION

In the past century, and especially during the past 50 years, a great amount of information on the agrometeorology of pasture and livestock production has been accumulated. All of this information is available to learned technologists. To determine how much of this information is needed for operational planning and management of pasture and livestock production, is the primary purpose of this report. The report is also concerned with how the needed information should be provided. The individual farmer's need is determined by the by cultural, social, economic and physical environment of the farm. These factors should ideally be taken into account but it is not possible in this report to deal comprehensively with all of the relevant factors. For the purposes of the report it is assumed that the farmer has received technical instruction and is motivated by considerations of technical efficiency. He is dependent on, and immediately receptive of management recommendations handed down by the expert technologist. As well as the direct personal interest of the individual farmer, society has an interest in livestock production. For economic, social and health reason, society must protect its food supplies and environment at a continental level or within national states. It is important to recognise this because, in general, farmers cannot use meteorological information directly. The trend for government in the temperate zone to off load responsibility for society to the private sector means that market forces will determine the availability of the necessary services in future.

A survey was made, using the services of the World Meteorological Organisation, of the existing agrometeorological information provided in the various countries of the temperate regions. The results are used for comparison with the needs identified by the authors.

The approach to the assessment of agrometeorological requirements in the report is qualitative and in this it does not meet the terms of reference which requested a quantitative formulation and "in readily usable, user oriented, form". To achieve this would require a more substantial input of time and resources than was possible. The qualitative assessment made, however, is offered as a first step in the venture.
CHAPTER 1: THE BASIC ELEMENTS OF SYSTEMS OF LIVESTOCK PRODUCTION

1.1 SUMMARY

It is shown that the efficient conversion of herbage into animal product depends on the use of sward management systems which are adapted to the seasonal production pattern of herbage dry matter. The seasonal curve of herbage production is examined in terms of its effects on animal production systems in different regions. The basic elements of systems are identified and the impact of adjustments in production by management outlined.

1.2 INTRODUCTION

Output of animal product is the result of complex interactions between farmer inputs and the basic climate, land, soil and socio-economic resources available.

There is wide variation within the temperate climate regions in the basic production environment (i.e. climate, land, soil and socio-economic circumstances) which has resulted in the evolution of a variety of systems of animal production. It is not possible in this chapter to examine local systems in terms of their efficiency but an attempt will be made to outline the common basic elements of systems and to point to strategies for maximum efficiency.

There are two main components in the overall production process. The first component is herbage production. The second component - herbage utilisation - is the subject of this chapter. Animal production per hectare is primarily dependent on the amount of herbage produced but several studies have shown that the efficiency of utilisation of herbage is often a limiting factor (Walsh, 1982). Because of seasonal variation in herbage growth only part of the annual production of herbage can be utilised directly by the grazing animal. The remainder must be utilised by cutting the herbage and feeding it after a period of storage. The integration of the grazing and cutting programmes constitutes a system. The efficiency of a system depends on the efficiency (a) of herbage recovery by the grazing animal (b) of herbage recovery in the cutting programme (c) of herbage storage and (d) of feeding of stored herbage. Overall system efficiency is finally determined by the extent to which the grazing and cutting programmes are complementary.

The definition of efficiency in these contexts is not simple. Reciprocal effects of the sward and the animal, each on the other, during grazing may lead to optimal grazing strategies that represent a compromise between the needs of the plant and the needs of the animal (Brereton, 1987). Similarly, cutting strategies commonly represent a compromise between yield and quality of the cut herbage. For this reason it is necessary to analyse systems in terms of their basic elements. There is a wide variation in herbage production potential within the temperate zone due to climatic variation. It has been estimated that the potential dry matter production of temperate type grassland, with moderate levels nitrogen use (circa 250 N kg ha\(^{-1}\) annum\(^{-1}\)) and with monthly harvests, varies from less than 10 t ha\(^{-1}\) annum\(^{-1}\) to approximately 15 t ha\(^{-1}\) annum\(^{-1}\) between northern and southern regions of Europe of example (Bouman et al., 1996). All areas exhibit similar patterns in the seasonal distribution of growth. On the basis of these patterns the year may be divided into three periods. There is a period in Spring/early summer when growth rates are
greatest. In the following summer/autumn period growth rates are reduced and then there is the winter period of little or no growth. Climatic factors are mainly responsible for this pattern but plant physiological factors associated with the alternation of the reproductive and vegetative states of the sward are also involved (Behaeghe, 1979; Parsons and Robson, 1982).

1.3 BASIC ELEMENTS OF SYSTEMS

Annual total herbage production determines stocking rate. For each region a basic potential stocking rate may be calculated on the basis that each livestock unit (500 kg LW) consumes herbage dry matter equivalent to 2.6% of bodyweight daily and that all of the herbage is consumed annually (i.e. 100% utilisation efficiency). From this potential stocking rate may be calculated a daily herd demand. When the daily herd demand is compared with the daily herbage growth rate it becomes possible to identify and quantify the basic elements of a system. In all regions there is a period when current herbage growth is sufficient to satisfy current herd demand and this period may be defined as the grazing period. The remaining period of the year, during which surplus herbage from the grazing period is fed, is the indoor feeding period. The time of availability of surplus herbage during the grazing period generally occurs in spring/early summer. The strict definition of the grazing period as the period when growth equals or exceeds current herd demand must be modified to take account of the fact that growth occurring late in the year and not grazed may be lost to senescence and decay in winter. For this reason the grazing season is defined as beginning when current growth first exceeds herd demand and ending when growth is less 50% of demand. Therefore, it is necessary, in order to maintain target performance, to use part of the grazing surplus to supplement grazed herbage at the end of the grazing season. It is necessary to identify the end of season period of supplementation as a separate element in systems because it can become a significant feature in areas where summer drought occurs (i.e., in continental Europe generally and in Mediterranean areas particularly), (Brereton et al., 1997). The shape of the seasonal growth curve also has a significant impact on conditions at the start of the grazing period. Herbage growth in late winter/early spring contributes to the herbage available at the start of the grazing in spring. It constitutes an initial surplus since, by definition, current growth is adequate to meet the current needs of the herd. The size of this pre-season accumulation affects the proportion of the total area that is required for grazing at the start of the grazing period and consequently has an impact on the area of the cutting programme.

Each animal production system must operate in the framework of the five components which have been identified - total herbage production, potential stocking rate, length of grazing period, supplementary feed at pasture and initial feed surplus. Estimates of each component have been made for selected locations in Europe (Table 1.1), (Brereton et al., 1997). At comparable levels of farm input the sites with higher herbage growth/stocking rate have a basic efficiency advantage but variation in other system components, which reflect differences in seasonal distribution of growth, also affect overall system efficiency. A shorter grazing season implies that more herbage has to be cut, stored and fed. Consequently more energy is required to operate the system. The same applies in the cases where summer supplementation is necessary. Where the area required for grazing at the start of the season is greater, than it becomes necessary to delay, or reduce the area of, the first silage cut. As a result silage yields are reduced.
The purpose of this analysis is to illustrate the basic features of the seasonal growth curve and how they influence the development of a grazing system. For clarity, the analysis has been simplified. For example, no allowance is made for differences in herbage growth on grazed compared to cut swards. Similarly, no allowance is made for losses of harvested herbage during storage and feeding.

<table>
<thead>
<tr>
<th>Site</th>
<th>Annual Herbage (DM t/ha/ann)</th>
<th>Potential Stocking Rate (LU/ha)</th>
<th>Length Grazing period (Months)</th>
<th>Supplementary. Feed at Grazing (kg/animal)</th>
<th>Initial Surplus area (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cahirciveen (IRL)</td>
<td>13.05</td>
<td>2.75</td>
<td>6.75</td>
<td>135</td>
<td>57</td>
</tr>
<tr>
<td>Falmouth (UK)</td>
<td>12.34</td>
<td>2.60</td>
<td>6.95</td>
<td>127</td>
<td>55</td>
</tr>
<tr>
<td>Angers (FR)</td>
<td>11.39</td>
<td>2.40</td>
<td>7.45</td>
<td>254</td>
<td>40</td>
</tr>
<tr>
<td>Altamura (IT)</td>
<td>11.39</td>
<td>2.40</td>
<td>8.60</td>
<td>800</td>
<td>52</td>
</tr>
<tr>
<td>Schleswig (DFR)</td>
<td>9.96</td>
<td>2.10</td>
<td>6.05</td>
<td>91</td>
<td>27</td>
</tr>
</tbody>
</table>

1.4 VARYING OUTPUT

Before considering strategies for grazing and conservation within the above framework a general evaluation will be made of some of the effects which result from changes in the basic level of annual herbage production - by the use of fertiliser for example. Any stimulation of annual total herbage production will result in a proportional increase in the potential stocking rate and any effect on the seasonal pattern of growth will have corresponding effects on the other system components.

An increase in nitrogen input from moderate to high levels will be expected to increase the potential stocking rate through its effect on herbage production. However, the growth promoting effect is proportional to the growth potential of the sward and consequently most of the increased production will be obtained earlier in the grazing season. (Prins, 1983). This assumes that the increased fertiliser is applied uniformly across the season. Growth increases later in the grazing season will be relatively small and less than proportional to the increased stocking rate. A greater requirement for supplementary feed would result and the grazing period would end earlier. Similarly, the fertiliser effect on growth in the period before grazing begins would advance the start of grazing but the area not required for grazing at the start would be reduced.
Where all of the annual herbage is being utilised (i.e. at optimal stocking), if the stimulation of herbage production is restricted to one part of the system - the cutting area for example - the increased herbage production cannot be fully utilised to increase the stocking rate. Herbage production in the grazed part of the system is unchanged so that an increase in stocking rate requires an increase in the proportion of the area available for grazing and a reduction in the cutting area.

The analysis underlines the need for the adoption of a whole-system approach. The application of these principles for the management of grazing systems is hampered in practice because of a lack of control of the seasonal growth curve due to weather variation.

1.5 GRAZING STRATEGY

The diet of the grazing animal is almost entirely composed of leaf even when grazing pressure is high (O'Sullivan, 1984). In swards the leaf is concentrated in an upper horizon. A lower horizon is composed mainly of stem and dead material. The leaf is more digestible than stem and dead material so that the digestible nutrients of the sward are concentrated in the upper horizon. On the basis of these considerations an 'available' fraction of the standing crop of herbage may be defined as the upper leafy horizon and harvest efficiency may be defined in terms of the extent to which this upper horizon is utilised.

The ability of an animal to prehend herbage close to the ground is limited (Demmert et al., 1995). Herbage intake by bovines is restricted when sward height is less than approximately 70 mm. The critical height for sheep is lower, approximately 50 mm. Therefore, to control grazing or utilisation efficiency under field conditions, it is also necessary to control the structure of the sward so that the position of the upper horizon is always above the height at which intake becomes restricted. The position of the upper leafy horizon can be lowered or elevated as grazing pressure is increased or decreased (Jackson, 1975). When grazing pressure is decreased not only is the upper horizon raised, but also the boundary between the upper and lower horizons becomes diffuse so that part of the leafy material occurs in the lower horizon and therefore becomes relatively inaccessible to the animal.

Although total dry matter production is greater under low than under high grazing pressure the net production of green leaf (which constitutes the diet of the grazing animal) is relatively unaffected by grazing pressure (Bircham and Hodgson, 1983). These considerations indicate that efficiency in animal production depends on the farmer's ability to control the sward animal interface.

1.6 CUTTING STRATEGY

During the grazing season overall land management must be dictated primarily by the grazing programme. The farm stocking rate is determined by the total annual herbage production of the farm from grazing and cutting and the role of the cutting programme is to harvest all the material not required for grazing. From the earlier discussion of the grazing strategy it is evident that the area available for cutting varies continuously through the season. Alternative approaches to the cutting programme may be adopted according to prevailing circumstances. This is exemplified by a comparison of the Dutch and Irish system (Brereton et al., 1984).
The climate and annual herbage production potential in both countries is broadly similar but there is a significant difference in winter temperatures. As a result of these differences winter growth is severely restricted in the Netherlands compared to that in Ireland.

In the absence of winter growth in the Netherlands the accumulation of dry matter prior to the start of the grazing season is limited. In contrast, in Ireland there is significant growth in this period. In the Irish situation the herbage available per paddock at the start of the grazing season is approximately double the daily herd requirement at the start of the grazing season (Table 1.2). Only 50% of farm area is required for grazing. In contrast, in the Netherlands, the feed available per paddock is only 1.5 times the daily herd requirement. Thus 75% of the farm is required for grazing and only 25% is available for silage production initially. In the Netherlands the silage area is varied during the season in line with current grass growth. In Ireland the area set aside for silage is initially large and is decreased later in the season as herbage growth declines. Throughout the silage cutting period paddocks may be added to or withdrawn from the silage area as dictated by the demands of the grazing herd.

With modern machinery the control of efficiency in the cutting programme is straightforward. However, weather variations can seriously affect the programme. The primary objective is to achieve maximum harvest of digestible nutrients from the herbage available for cutting. The total harvest of digestible nutrients is the product of the dry matter harvested and its digestibility. In temperate grassland, cutting practice must make a compromise between yield and quality. Yield increases and digestibility decreases as the duration of the growth period increases. This is particularly the case earlier in the season when the crop is in the reproductive state.

<table>
<thead>
<tr>
<th>Date</th>
<th>% of farm closed for cutting</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>IRL</td>
</tr>
<tr>
<td>Mid April</td>
<td>50</td>
</tr>
<tr>
<td>1 May</td>
<td>50</td>
</tr>
<tr>
<td>Mid May</td>
<td>50</td>
</tr>
<tr>
<td>1 June</td>
<td>50</td>
</tr>
<tr>
<td>Mid June</td>
<td>25</td>
</tr>
<tr>
<td>1 July</td>
<td>25</td>
</tr>
<tr>
<td>Mid July</td>
<td>25</td>
</tr>
<tr>
<td>1 August</td>
<td>0</td>
</tr>
<tr>
<td>Mid August</td>
<td>0</td>
</tr>
<tr>
<td>1 September</td>
<td>0</td>
</tr>
<tr>
<td>Mid September</td>
<td>0</td>
</tr>
<tr>
<td>1 October</td>
<td>0</td>
</tr>
</tbody>
</table>
The present analysis is based on the farm that is self-sufficient. Herbage, grazed or cut, is the only feed source. Obviously where supplementary feed is imported into the system a reappraisal of the potential stocking rate becomes necessary because the total feed available in the system is increased. Imported feed is used to increase the potential stocking rate and to manipulate the seasonal pattern of feed supply. However, to do this efficiently it is necessary to have a clear understanding of the unsupplemented system.
CHAPTER 2: REGIONAL AND YEAR-TO-YEAR VARIATION IN PRODUCTION

2.1 SUMMARY

It is illustrated the extent and the practical significance for management of the variation in the primary production component of livestock systems using an Irish example.

2.2 INTRODUCTION

The variability of grass production in Ireland has not been studied in detail. This is probably a reflection of the fact that the island is relatively small, and compared with mainland Europe, for instance, there is little variation (Brereton et al., 1997). It probably also reflects the fact that the average stocking rate in Ireland is significantly less than the potential stocking rate. Thus, on the average farm, grass production exceeds demand and unmanaged variations in grass production have no major impact on management.

However, farms which are stocked to potential and where grass provides more than 90% of the annual diet of cows make an important contribution to the national output of animal products. On these farms year-to-year variability in grass production has great significance because the replacement of a grass deficit by purchased feed is expensive. In systems that are heavily dependent on grazed grass increases, it is important to know precisely how much grass is produced, how this production is distributed across the season and how it varies between locations and years. Apart from its significance for commercial farming, this information would also be important for the development of management systems to control the ecology of destocked land.

In this chapter the effects of meteorological factors on grass production are examined and an assessment is made of the consequences for intensive production systems. This analysis therefore makes use of a growth model (Brereton et al., 1987). The model estimates are supplemented by measurements from a limited number of experimental trials.

2.3 REGIONAL VARIATION MEASURED EXPERIMENTALLY

In Ireland the annual yield of dry matter on well-drained soil varies broadly from the south-west to the north-east (Brereton, 1995). A diagonal line from the north-west to the south-east was used to subdivide the sites (Table 2.1). The overall trend in yield was from 13 t ha\(^{-1}\) to 11 t ha\(^{-1}\) between the regional extremes. This indicates a range in yield that is about 17% of the average for all well-drained sites.

<table>
<thead>
<tr>
<th>Table 2.1: Annual grass yields (t ha(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>------</td>
</tr>
<tr>
<td>Average</td>
</tr>
<tr>
<td>S.D.</td>
</tr>
<tr>
<td>Range</td>
</tr>
</tbody>
</table>

In the west, where annual rainfall is greater, yields on wet soils were reduced by about 2 t ha\(^{-1}\) compared to well-drained soils. In the lower rainfall areas of the east this difference between wet and dry soils was about 1 t ha\(^{-1}\). The composition
of the vegetation varied between sites. Among the well-drained sites the dominant species included the common agricultural grasses and white clover. In contrast, at the wet sites rushes were dominant. The smaller difference in the yield at wet and dry sites in the lower rainfall areas of the east suggests that the variation in yield between wet and dry soils was due to both rainfall and vegetation differences.

2.4 YEAR-TO-YEAR VARIATION MEASURED EXPERIMENTALLY

There is considerable variation between years (Table 2.2). At a site in South-Central Ireland, the range from highest to lowest annual yields was 7.5 t ha\(^{-1}\). Apart from the exceptional yield in 1988 the distribution was approximately normal. When the data for 1988 are excluded, the mean yield was 12.9 t ha\(^{-1}\) and the range was still great, 3.5 t ha\(^{-1}\) or 27.5 of the mean.

Although the geographical separation of the sites contributed to the yield differences, the greater yields at the South-Central site reflect mainly the much higher nitrogen regime (600 kg ha\(^{-1}\)) and a longer interval between harvests (four weeks) used in these trials compared to grazing trials at the South-East coastal site (zero and 250 kg N ha\(^{-1}\) and three weeks, respectively).

Despite these differences, the variation in yield recorded under grazing between 1985 and 1988 was similar in relative terms to the variation measured at the South-Central site for the same years. The range in yield was greater than 20% of the mean yield at both the 250kg and zero nitrogen treatments. At somewhat greater than 20% of the average, the year-to-year variation is on the same scale as the regional variation shown above for well-drained soils.

<table>
<thead>
<tr>
<th>Year</th>
<th>South-Central site 600 kg N*</th>
<th>South-East Coastal site 250 kg N</th>
<th>South-East Coastal site Zero N</th>
</tr>
</thead>
<tbody>
<tr>
<td>1982</td>
<td>11.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1983</td>
<td>14.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1984</td>
<td>12.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1985</td>
<td>13.7</td>
<td>8.6</td>
<td>6.3</td>
</tr>
<tr>
<td>1986</td>
<td>12.5</td>
<td>7.2</td>
<td>5.0</td>
</tr>
<tr>
<td>1987</td>
<td>14.4</td>
<td>7.4</td>
<td>5.3</td>
</tr>
<tr>
<td>1988</td>
<td>18.4</td>
<td>8.8</td>
<td>5.7</td>
</tr>
<tr>
<td>1989</td>
<td>12.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1990</td>
<td>12.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1991</td>
<td>10.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>13.4</td>
<td>7.9</td>
<td>5.6</td>
</tr>
<tr>
<td>S.D.</td>
<td>2.1</td>
<td>0.8</td>
<td>0.6</td>
</tr>
<tr>
<td>Range</td>
<td>7.5</td>
<td>1.7</td>
<td>1.3</td>
</tr>
</tbody>
</table>

*Annual nitrogen fertiliser application (kg ha\(^{-1}\))
2.5 MODEL ESTIMATES OF VARIATION IN GRASS PRODUCTION

Regional distribution of annual dry matter yield given by a model showed the same broad trend in the distribution and level of yield as was shown by the experimental data. The model estimates were based on a more even distribution of sites so that it is possible to examine the regional pattern in more detail.

Within the south-west region yields varied between 15t ha\(^{-1}\) and 12t ha\(^{-1}\). In both the north-west and the south-west, yields varied from 13t ha\(^{-1}\) at the coast to 11.5t ha\(^{-1}\) inland. In the north-east yields varied between 12t ha\(^{-1}\) and less than 10.5t ha\(^{-1}\), following the overall south-west/north-east yield trend. The similarity between the pattern shown by the model and measured data indicates that the regional trends are controlled mainly by the meteorological factors. Physical differences between soils and vegetation factors appear to be less important. The use of the model in the context of year-to-year variation in yield is limited to a comparison with the measured yields for the years 1985-8 (Table 2.3). The model estimates were based on the meteorological data from the South-East coastal site and the values were scaled to simulated the management used at the site. This was a three-week harvest cycle and 250 kg N ha\(^{-1}\) annually. The model estimates were 10% larger than the measured values but the year-to-year trend was practically the same. The South-Central site data followed the same general pattern. Differences in detail between the trends at the two sites probably reflect regional differences in meteorological conditions.

<table>
<thead>
<tr>
<th>Year</th>
<th>South-Central site (N = 600 kg)</th>
<th>South-East Coastal site (N = 250 kg)</th>
<th>Model* (N = 250 kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1985</td>
<td>13.7</td>
<td>8.6</td>
<td>9.2</td>
</tr>
<tr>
<td>1986</td>
<td>13.5</td>
<td>7.2</td>
<td>8.2</td>
</tr>
<tr>
<td>1987</td>
<td>14.4</td>
<td>7.4</td>
<td>8.7</td>
</tr>
<tr>
<td>1988</td>
<td>18.4</td>
<td>8.8</td>
<td>9.9</td>
</tr>
</tbody>
</table>

*Using meteorological data from South-East Coastal

2.6 TECHNICAL AND ECONOMIC IMPACTS OF YIELD VARIATION

The structure and functioning of a commercial dairy farm in Ireland may be summarised as follows. From each hectare three cows yield a total of 3300 gallons of milk. This output is supported by the use of 400 kg of nitrogen to produce 13 t of grass (silage and grazing). As well as the grass produced on the farm, 1t of meals is purchased from off the farm. The cows calve in early spring and the meals are needed to supplement silage until the herd begins grazing in March/April. From then until October/November grazed grass is generally the only feed provided. The total energy of the grazed grass, silage and meals determines the number of cows that can be fed, and as the grass feeds represent the greater part of the total feed it is obvious that any variation in grass production will affect the number of cows
and the milk that is produced or else will affect the amount of meals to be purchased. The relative cost of meals, silage and grazed grass is 5:3:1, respectively so that costs are least in situations where the proportion of grazed grass in the annual diet is greatest. Thus, most milk will be produced per hectare at least cost in the situations where annual grass production is greatest, the grazing season begins earliest and grass growth is spread over the year at a rate that allows grazing to continue without supplementation for the longest period.

The seasonal pattern of grass growth rates given by the model was used to calculate the number of days when the growth rate exceeded 40 kg dry matter ha\(^{-1}\) day\(^{-1}\). This was used as a gross measure of the regional differences in the length of the grazing season. The model data were also used to estimated the date in spring when yield was sufficient for grazing to begin (1500 kg dry matter ha\(^{-1}\)). The regional trend for turn-out date was similar to the trend for total annual yield. Turn-out date was earliest in the extreme south-west and was progressively later towards the north-east. In contrast, the length of the grazing season was greatest in the north-west and tended to decrease south-eastwards.

It is possible to adapt the basic structure of a system of management to deal with temporary shifts in the level of grass production. However, such adaptations are not commonly used. As a result, fluctuations in grass production between years are reflected in reciprocal fluctuations in the use of purchased feedstuffs (Table 2.4). The data are taken from a study of the livestock feed balance for Ireland for the years 1983-9 (McLoughlin, 1991). The grass data are national totals of grazed grass, silage and hay, calculated using the model described above. The totals are for yearly periods beginning in July and they take into account fluctuations in crop areas and nitrogen use. The data on the supply of non-grass feed shown in Table 2.4 are the total of all types of feed, both native and imported, used by the dairying section of the livestock industry. The year-to-year trend in grass supply follows the pattern shown in Table 2.4. The trend in use of non-grass feed follows a reciprocal pattern. In the two years 1985-6 and 1986-7, when grass production decreased, there was a corresponding increase of more than 170,000 tonnes in the use of purchased non-grass feedstuffs. The monetary value of these extra feedstuffs would be in excess of IRE20 million.

<table>
<thead>
<tr>
<th>Year</th>
<th>Grass</th>
<th>Non-grass</th>
</tr>
</thead>
<tbody>
<tr>
<td>1983/4</td>
<td>25.01</td>
<td>1.01</td>
</tr>
<tr>
<td>1984/5</td>
<td>25.87</td>
<td>1.11</td>
</tr>
<tr>
<td>1985/6</td>
<td>23.92</td>
<td>1.27</td>
</tr>
<tr>
<td>1986/7</td>
<td>24.73</td>
<td>1.29</td>
</tr>
<tr>
<td>1987/8</td>
<td>29.28</td>
<td>1.09</td>
</tr>
<tr>
<td>1988/9</td>
<td>27.49</td>
<td>1.11</td>
</tr>
</tbody>
</table>

2.7 DISCUSSION

The evaluation of the overall effect of the regional variation in grass production is complicated by the fact that the trends for all three of the important aspects of
production are not correlated. However, as turn-out date and annual yield are correlated, it is possible to obtain a general regionalisation of the island in terms of yield and length of grazing season. The most advantaged area in the South-west, which enjoy all the advantages of high yield, early turn-out and a long grazing season. The least advantaged area is the North-east where the yield is relatively low, the grazing season begins late and the season is short.

The analysis indicates that the variation in grass growth regionally and yearly is sufficiently great to have a significant impact on the technical and the economic performance of farms. In this study it is not possible to precisely quantify the relevant responses that occur at farm level, but the results suggest that the administration of agricultural policy, should take these into account. Similarly, the future development of systems of animal production would need to take account of the local limitations as well as opportunities presented by the regional variation in grass production patterns.

This analysis is primarily concerned with grassland farming on well-drained lowland. It is important to recognise that a large proportion of farms are located in basically less favoured environments - on wet land and on hills.
CHAPTER 3: SILAGE PRODUCTION

3.1 SUMMARY

The impact of weather on production is described. Good quality silage or hay is difficult to achieve because weather often prevents quick and uninterrupted harvesting or drying of the crop. (The authors are indebted to Dr. Padraig O’Kiely, Teagasc, who contributed most of the material in this chapter).

3.2 INTRODUCTION

Because grass growth is seasonal, with high production in summer and little or no production in winter, it is normal to conserve surplus summer grass to feed to livestock in winter. Drying grass to make hay was the traditional method of conservation but over the past 30 years this has gradually been replaced by ensilage. The main reasons for this change have been the relative independence of weather conditions associated with silage compared with hay production, together with the availability of efficient methods of harvesting, storing and feeding silage and the requirement for a reliable winter feed source as livestock production became more intensive.

3.3 SILAGE PRODUCTION

The growth of the silage crop follows the same seasonal pattern as the grazed crop. The rate of growth during the growing season is however always greater because it is less frequently interrupted by harvesting. The grazed crop is usually harvested at 3-week intervals so that the crop never develops a full leaf canopy. The more leaf that the grass crop has the greater use it makes of sunlight and the greater it’s growth rate. In the silage crop the yield is able to develop and a correspondingly high growth rate is possible. In contrast to the annual crop yield that is usual under grazing the annual yield of grass cut 4 or 5 times at 6-week intervals may be greater by 75%. Part of the difference is due to the higher rates of nitrogen use but the longer growth period is important. Compared to the 100 kg/ha/day that may be achieved under grazing in May-June the silage crop can achieve about 150 kg/ha/day. For short periods it can be as high as 200 kg/ha/day.

Weather does not have a major effect on silage harvest date, especially first cuts. In the northern hemisphere, in seasons when March and April are both significantly colder than normal (say average daily temperature 1°C below normal - and this would be very unusual) then the date of first ear emergence in early May is delayed by about 2 weeks. But even in such a year the development of ear emergence at the end of May is delayed by only a day or two. Although harvest date is relatively unaffected, the yield at harvest can be significantly affected by weather. The yield of first cut silage can vary by as much as 3 tonnes DM/ha\(^1\) as the result of temperature and radiation variations between years.

An important effect of weather is on the sugar content of the crop at harvest. This is important because ease of achieving good silage preservation is closely related to the sugar content of the crop at harvest. Sunlight intercepted by the leaves results in the production of sugar by photosynthesis. The sugar is used to produce new growth. However, in cold weather the crop is not able to use the sugar as fast as it is produced and sugar accumulates in the plant. Sugar levels will tend to rise when the days are clear and temperatures are low (especially at night). In
warm overcast weather the sugar levels will tend to be low. This phenomenon may also occur in the grazed sward and could explain why animal performance is less than expected in warm wet summers when grass is plentiful.

3.4 SILAGE QUALITY

The main factor affecting silage quality (dry matter digestibility - DMD) is the quality of the grass harvested. Top quality silage can only be made from crops of leafy grass. Harvesting stemmy grass automatically means poor quality silage. Cattle and sheep perform much better when fed silage of high digestibility. Over the range of digestibility from 60 per cent DMD (stemmy silage) to 75 per cent DMD (leafy silage) animal performance on silage is tripled, with silage intake increasing slightly and feed conversion efficiency improving markedly (Table 3.1). As grass becomes more mature and stemmy and heads out, its digestibility falls off quickly (0.3 to 0.6 units DMD per day). For this reason top quality silage is made from grass cut before seed-heads emerge (mid to late May for the first cut, depending on locality and sward type).

When grass is harvested for silage-making it is still a living plant which would rot were it not preserved properly. The first essential in silage-making is therefore to put the grass into an air-free environment (sealed silo) as quickly as possible to terminate all rotting processes which require oxygen. The second essential is to control the fermentation which takes place under these conditions and to make sure it is a desirable one which produces lactic acid from the fermentation of sugars. This is facilitated in farm practice by (a) quick filling, perfect sealing of the silo (completely air-free storage is essential), (b) ensiling only "clean" grass (contamination by soil, slurry etc. makes bad preservation likely), (c) aiding preservation when needed, either by applying an additive or by wilting.

<table>
<thead>
<tr>
<th>Digestibility (% DMD)</th>
<th>60</th>
<th>65</th>
<th>70</th>
<th>75</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appearance</td>
<td>Stemmy</td>
<td>V.</td>
<td>Leafy</td>
<td>All Leaf</td>
</tr>
<tr>
<td>DM intake, kg/day</td>
<td>7.0</td>
<td>7.6</td>
<td>8.3</td>
<td>9.0</td>
</tr>
<tr>
<td>kg/100 kg 1 wt</td>
<td>1.66</td>
<td>1.75</td>
<td>1.85</td>
<td>1.94</td>
</tr>
<tr>
<td>LWG, kg/day</td>
<td>0.31</td>
<td>0.49</td>
<td>0.66</td>
<td>0.83</td>
</tr>
<tr>
<td>Carcass gain kg/day</td>
<td>0.15</td>
<td>0.27</td>
<td>0.37</td>
<td>0.51</td>
</tr>
<tr>
<td>Carcass gain/intake kg/tonne</td>
<td>21.8</td>
<td>36.6</td>
<td>47.1</td>
<td>56.8</td>
</tr>
</tbody>
</table>

3.5 WEATHER HAS A MAJOR IMPACT ON SILAGE PRESERVATION

Wet weather at harvest can slow the rate of silo filling considerably and make it much more difficult to ensile grass without soil contamination. In very dry weather, slurry spreading can often increase the chance of contamination by harmful micro-organisms in slurry remaining on the grass. Warm, overcast and wet weather tends to reduce the level of fermentable sugar in grass which makes adequate lactic acid production more difficult.
Since silage is an expensive feed to produce and constitutes the major feed ingredient given to most beef cattle or dairy cows in winter, it is important to use it efficiently. This means (a) ensuring that animals can eat as much as they want and (b) keeping waste in the silo and feed trough to a minimum. Restricting wastage at feeding time depends on (a) silage management and (b) weather. Cold weather restricts the deterioration of exposed silage.

<table>
<thead>
<tr>
<th>Table 3.2 : Effect of ambient temperature and standard of preservation on aerobic deterioration</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>---------------------------</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>DM loss (%)</td>
</tr>
<tr>
<td>Days to pH rise</td>
</tr>
<tr>
<td>Days to temp. rise</td>
</tr>
<tr>
<td>Accum. temp. rise above ambient</td>
</tr>
</tbody>
</table>

Good preservation : pH < 4.2; Bad preservation : pH > 4.2

3.6 SILAGE EFFLUENT

Silage effluent is produced in large amounts where silage is not wilted. Besides representing a loss of nutrients from the silo, silage effluent has a very high pollution capacity if it enters surface or ground water. However, silage-making systems within which effluent is produced as a by-product are likely to continue to dominate grass conservation practice in the more humid regions of the temperate climate zone for the foreseeable future. Consequently effluent collection and disposal on all farms have to be managed in a sensible and effective manner which prevents harmful effects on the environment.

Grass produces anywhere between 0 and 300 litres of effluent per tonne when ensiled. Grass wetness, which is strongly related to weather conditions around harvesting, is a major determinant of the amount of effluent produced. At present total collection and spreading of effluent on grassland is the most realistic approach to dealing with silage effluent. Provided it is not spread too heavily in any area or too close to freshwater sources, pollution is avoided. In addition, the effluent has a fertiliser value which, although small, is a bonus. An opportunity exists also to reduce the volume to be spread and to realise the feed value of the effluent, by feeding it to livestock. Research has shown good quality uncontaminated effluent to be quite acceptable to cattle, with animals typically consuming 15-30 litres per head daily. This has been consistently reflected in additional carcass gains in trials with beef cattle. The incorporation of absorbents with grass as it is ensiled, although expensive, may be a practical solution for some farms.
CHAPTER 4: THE IMPACT OF WEATHER ON LIVESTOCK

4.1 SUMMARY

The effects of extremes of weather on the performance and welfare of livestock are described. Both housed and field-grazing livestock are affected. (The authors are indebted to Mr. Brendan Lynch, Teagase, who provided the material for this chapter).

4.2 INTRODUCTION

Farm animals maintain a steady body temperature of 38-40°C and they do this by regulating heat production and heat loss. In cold conditions animals will conserve heat by lying down, by huddling, by seeking shelter, by eating more and by using food for heat instead of growth or milk production. They will also develop longer hair coats. In hot conditions animals eat less, pant, seek shade and (especially pigs) wallow in pools or even in excreta. Animals will tolerate extremes of heat and cold better if they are accustomed gradually to the conditions (Clark, 1981; Curtins, 1981; Phillips and Piggins, 1992).

Low temperature in itself does not affect the animal if it has had an opportunity to acclimatise by developing a natural thick coat of hair or wool but when the animals coat is wet, energy is expended in the evaporation of water from the coat and this effect increases in wind. The outwinted bovine animal can survive at temperatures as low as -20°C in calm sunny conditions (Webster, 1974). But in wet windy conditions the temperature required to maintain performance for the same animal may be 2°C. This underlines the importance of shelter for animals even in relatively mild winter climates.

4.3 WIND CHILL IN SHEEP AND LAMBS

Adult sheep when full fleeced are very tolerant of cold, even down to -10°C. But shorn sheep may be chilled at 20°C especially if feed intake is low. New-born lambs, especially smaller lambs eg. twins or triplets, are particularly at risk. Once the lamb has dried out and suckled, its tolerance to cold rapidly improves. Suckling is extremely important. Colostrum provides the energy to combat cold as well as protective antibodies against disease. Lamb mortality is commonly the result of exposure to cold wet wind soon after birth before they have developed a protective coat of dry wool. Usually these animals have also failed to suckle. The degree of exposure varies between fields within a farm and it is important to remember that the identification of a sheltered site should take account of all the weather factors - wind, rain and temperature. Nutrition is obviously of primary importance. The body reserves of a lamb are limited. They are only sufficient to support the energy requirements of a 3 kg animal for about 6-15 hours (Alexander, 1962).

The incidence of pleurisy/pneumonia lesions in sheep is closely correlated with weather. The combined effects of rain, wind, relative humidity and temperature on the level of the risk or pleurisy to the sheep can be calculated as a 'rain/windchill' factor (McIlroy et al., 1988). The factor (RW) is calculated as follows:

\[ RW = W \times H \times (35 - T) + 50 \times R \]

where \( W \) = wind speed (knots); \( H \) = relative humidity (%); \( T \) = air
temperature (°C); \( R \) = rainfall (mm).

4.4 WIND CHILL IN STEERS

These effects of weather also have a significant effect on animals after turnout in Spring. Average daily live weight gain has been shown to vary between years from greater than 1 kg/day to less than 0.1 kg/day for steers (300 kg livestock) during the first grazing rotation in spring in south-east Ireland (Table 4.1). This has been largely attributed to the effects of temperature combined with wind and rain (Ryan and O’Keeffe, 1985).

Cattle are very tolerant to cold especially if dry, the performance of a high yielding cow may be unaffected by temperatures as low as -40°C. However, immature animals, for example a new born calf, is most comfortable at 10°C. Wind, driving rain and mud are most serious threats to cattle especially in spring when animals may have shed their winter hair coats. High temperatures in summer may cause cattle to change their behaviour so that they graze more in the cooler times of the day (Curtis, 1981).

<table>
<thead>
<tr>
<th>Year</th>
<th>Windspeed m/s</th>
<th>Rainfall mm/day</th>
<th>Temperature °C</th>
<th>LWG kg/day</th>
</tr>
</thead>
<tbody>
<tr>
<td>1982</td>
<td>3.58</td>
<td>0.04</td>
<td>8.9</td>
<td>1.5</td>
</tr>
<tr>
<td>1977</td>
<td>3.98</td>
<td>2.80</td>
<td>8.2</td>
<td>1.2</td>
</tr>
<tr>
<td>1984</td>
<td>3.80</td>
<td>1.29</td>
<td>9.5</td>
<td>1.1</td>
</tr>
<tr>
<td>1980</td>
<td>3.67</td>
<td>0.71</td>
<td>9.1</td>
<td>0.7</td>
</tr>
<tr>
<td>1981</td>
<td>3.71</td>
<td>1.55</td>
<td>8.1</td>
<td>0.6</td>
</tr>
<tr>
<td>1983</td>
<td>4.11</td>
<td>3.39</td>
<td>7.5</td>
<td>0.6</td>
</tr>
<tr>
<td>1979</td>
<td>4.47</td>
<td>3.43</td>
<td>7.7</td>
<td>0.5</td>
</tr>
<tr>
<td>1978</td>
<td>3.26</td>
<td>2.02</td>
<td>7.9</td>
<td>-0.6</td>
</tr>
</tbody>
</table>

4.5 PIGS

Pig production in the temperate zone is most often indoors on unbedded floors with heating for suckling and newly weaned pigs. Houses tend to be well insulated and have controlled ventilation so that temperature is controlled at about 20°C or greater for younger pigs. Heat loss is greater in cold weather especially if windy conditions prevail. Many houses have natural ventilation where hot air rises through openings (chimneys) at high level and is replaced by cold air at low level. Still air conditions are uncommon and for about 90 per cent of the time wind forces air into the house through any available openings. New-born pigs frequently die from cold stress. They require about 30°C for comfort. Older pigs grow more slowly and use feed less efficiently if they are too cold. In hot conditions pigs eat less, grow more slowly and soil their lying area. In very warm summer conditions fertility may be depressed in boars (Le Dividich et al., 1992).
CHAPTER 5: GRAZING MANAGEMENT AND EFFICIENCY

5.1 SUMMARY

It is described how variability in herbage production during each year leads to inefficient utilization - because grazing pressure in not flexibly adjusted to meet variations in herbage available. This variation is controlled by weather.

5.2 INTRODUCTION

The output of animal production from a grassland system depends both on the amount of herbage produced and on the efficiency of its utilisation. High efficiency depends on the maintenance of an optimum balance between the herbage available and herd feed demand (Brereton, 1987). 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 sub-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.

5.3 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 efficiency of harvest and the efficiency of conversion of harvested herbage to animal product. Both efficiencies are controlled by grazing pressure, or herbage allowance.

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 live weight gain and the amount of herbage harvested, is zero at low herbage allowances when there is no live weight 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.

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 control of this interface
between the sward and the grazing animal is difficult.

5.4 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 leaf which is relatively accessible and a lower horizon composed of low digestible material which is relatively inaccessible by the animal. The height of the boundary between the two horizons can be controlled by grazing pressure. 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 have indicated that the rate of net herbage accumulation is not affected by a wide range of grazing pressures. 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 utilization 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 80 mm (Le Du et al., 1979) but the height below which performance is restricted will depend on the profile structure of the canopy. Animal performance is high when the grazed height is increasing progressively (when herbage growth exceeds consumption) and vice versa (Alcock et al., 1986). Experience with steers, grazing rotationally in perennial ryegrass swards, suggests that steady state conditions can be achieved only when grazing height is approximately 70 mm and animal performance is restricted to 1.0 kg ha\(^{-1}\) 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.

5.5 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) is determined by the average number of days grazing on a paddock (D) and the number of paddocks (P)
\[ Ri = D \cdot P. \] (i)

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

\[ D = G \cdot R_{r_i} / N \cdot I \] (ii)

and

\[ R_i = G \cdot R_{r_i} \cdot P / N \cdot I \] (iii)

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

\[ R_i = (G \cdot R_{r_i} + S) \cdot P / N \cdot I \] (iv)

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 (iv) -

\[ SP = (R_i \cdot N \cdot I) - (R_{r_i} \cdot G \cdot P) \] (v)

The analysis indicates the complexity involved in the management of tactical responses to unpredictable deviations in herbage growth from normal expectation.
CHAPTER 6: ANALYSIS OF THE EFFECTS OF WATER-TABLE ON A GRASSLAND FARMING SYSTEM

6.1 SUMMARY

The potential livestock output on wet soils, is limited because grass growth is reduced when soils are water logged. This results in a basic limitation of the amount of stock each hectare can support. The other major disadvantage of wet soils is their low trafficability of both livestock and machinery. The feed production and the feed harvest limitations are most severe at the beginning and end of the season with the result that grassland farmers on these soils are further disadvantaged by a short grazing season and a long indoor feeding period. Linear programming is used to design a grassland management strategy for these soils and to determine stocking potential. A mathematical model is developed which relates water-table to precipitation and evaporation. The use of the model to optimise tactical management on wet land is discussed.

6.2 INTRODUCTION

Almost one third of the lowland of Ireland is classed as wetland. The soil is usually a pseudogley with a perched water-table. The hydraulic conductivity of the subsoil is extremely low. The soils are used mainly for grassland farming. The herbage productivity of the soils is low. Furthermore, low trafficability, for both animals and machinery, is a major management problem. The trafficability problem persists intermittently through the season (Brereton and Hope-Cawdrey, 1988).

The level of the water table controls the capacity of the soil surface to carry traffic. As the water table rises the water content of the soil above the water table increases and its strength decreases. The strength of the surface begins to decrease when the depth to the water table is less than 0.3 m. The rise or fall in water table depth is the result of the balance between water entering the soil following rainfall, and the losses from the soil due to evaporation and drainage. In summer the rate of evaporation is about 3 mm per day. Average rainfall is only slightly less. In the wet soils the drainage rate is negligible so that under average conditions the water table would not change much. However, the week to week variation in rainfall is much greater than the variation in evaporation. As a result the water table can fluctuate widely from week to week. The surface can change from the trafficable to untrafficable state in a few days (Brereton and Hope-Cawdrey, 1988).

There is a considerable variation between years in the pattern of change in water-table depth and consequently, management is conducted in an environment of considerable uncertainty. This chapter examines the management strategies that are available under the restrictions imposed by these difficult soils.

6.3 FEED PRODUCTION

A comparison of herbage production on a wet drumlin soil with production expected on a well-drained soil, shows that on the wet soil feed production and therefore the amount of stock that can be supported per hectare is 29% less than on a well-drained soil (Brereton and Hope-Cawdrey, 1988), (Table 6.1). In both cases the annual level of N use was 250kg/ha.
Most of the loss of production occurred in the first part of the season, up to late May. This is the period of maximum productivity in normal well-drained soils. On the wet soil, the productivity in this period was reduced by 50%.

<table>
<thead>
<tr>
<th>Year</th>
<th>Well-drained</th>
<th>Wet</th>
</tr>
</thead>
<tbody>
<tr>
<td>1983</td>
<td>37.3</td>
<td>25.9</td>
</tr>
<tr>
<td>1984</td>
<td>45.1</td>
<td>32.9</td>
</tr>
<tr>
<td>1985</td>
<td>39.7</td>
<td>26.9</td>
</tr>
<tr>
<td>1986</td>
<td>34.7</td>
<td>25.4</td>
</tr>
</tbody>
</table>

### 6.4 SILAGE MANAGEMENT

Two consequences follow from the reduced productivity of wet soils in the period up to May. Firstly, turnout is delayed. Secondly, the area required for grazing in the period after turnout is greater than normal, so that the area available for first cut silage is reduced. This means that on wet soils winter feed depends largely on the second and later silage cuts. The seasonal pattern of land use for grazing and on the wet soil is compared in Table 6.2 with the pattern on a well-drained soil (in both cases for a spring-calving dairy herd). The patterns are based on linear programming. In both cases turnout was on March 15 and the grazing season ended on November 5 and the level of N use in both was 250kg/ha annually. As expected from the difference in feed production (Table 6.1), the number of cows that the wet soil was able to carry was about 30% less than on the well-drained soil.

Whereas the bulk of the winter feed was produced at the first cut on the well-drained soil, on the wet soil the first cut makes a relatively small contribution.

### 6.5 SUPPLEMENTATION

There is normally a need for supplementation after turnout and at the end of the season. The results show that the levels of supplementation on the wet soil were greater, even though the number of animals was less. The level of demand for supplementation at pasture at the two ends of the season may be reduced by shortening the grazing season. In Table 6.3 the system is re-designed for a grazing season beginning on April 5 and ending on October 15. In the re-designed system no supplementation was allowed in the period following turnout. In both the drained and undrained cases the stocking potential was constrained by herbage growth rates in the periods after mid-season. The constraint increased progressively and in the final period supplementation was necessary. The basic difference in the pattern of land use remained.
Table 6.2: Stocking potential, fraction of farm used for grazing or silage and level of supplementation as fraction of total diet. 120-day winter

<table>
<thead>
<tr>
<th>SR</th>
<th>Well-drained</th>
<th>Wet</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.35</td>
<td>1.74</td>
</tr>
<tr>
<td>16/3 - 4/4</td>
<td>0.81</td>
<td>0.46</td>
</tr>
<tr>
<td>5/4 - 25/5</td>
<td>0.54</td>
<td>0.46</td>
</tr>
<tr>
<td>26/5 - 6/7</td>
<td>0.54</td>
<td>0.46</td>
</tr>
<tr>
<td>7/7 - 17/8</td>
<td>0.75</td>
<td>0.25</td>
</tr>
<tr>
<td>1/8 - 15/10</td>
<td>1.51</td>
<td>0.00</td>
</tr>
<tr>
<td>16/10 - 15/11</td>
<td>3.93</td>
<td>0.00</td>
</tr>
</tbody>
</table>

6.6 WATER-TABLE AND TRAFFICABILITY

In the wet drumlin soils the depth to the water-table, measured from the soil surface, varies between 100 and 500 mm during the period March to October. The pattern of change in depth during the period differs between years. In some years it increases progressively over this range. In a dry year, it remains near 400 mm during most of the period. In other years it decreases progressively from about 400 mm during most of the period. These broad trends in each year are accompanied by large, short-term, variation. The growth of herbage is depressed when the water-table depth is less than 400 mm and trafficability is reduced when the depth is less than 320 mm, (Brereton and Hope-Cawdrey, 1988).

Table 6.3: Stocking potential, fraction of farm used for grazing or silage and supplementation as fraction of total diet. 171-day winter

<table>
<thead>
<tr>
<th>SR</th>
<th>Well-drained</th>
<th>Wet</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.35</td>
<td>1.74</td>
</tr>
<tr>
<td>5/4 - 25/5</td>
<td>0.43</td>
<td>0.57</td>
</tr>
<tr>
<td>26/5 - 6/7</td>
<td>0.54</td>
<td>0.46</td>
</tr>
<tr>
<td>7/7 - 17/8</td>
<td>0.75</td>
<td>0.25</td>
</tr>
<tr>
<td>18/815/10</td>
<td>1.50</td>
<td>0.00</td>
</tr>
</tbody>
</table>

The changes in the depth to the water-table are mainly due to the difference between evapotranspiration and infiltration of rainwater. The rate of vertical movement of water through the subsoil is extremely slow. Therefore, the change
in water-table depth may be estimated from

\[ W1 - W0 = \frac{(E-P)}{X} \quad (1) \]

where -

- \( W1 \) = final depth to the water-table, mm
- \( W0 \) = initial depth to the water-table, mm
- \( X \) = pore volume (air-filled at 1500 k Pa tension) as fraction of soil volume
- \( E \) = cumulative evapotranspiration in the period, mm
- \( P \) = cumulative infiltration in the period, mm

The relation provides a satisfactory simulation of the measured trends in water-table depth using an interval of one week. The pore volume fraction was taken as one third of the soil volume. Infiltration was assumed equal to precipitation to a maximum equivalent to 3 mm per day i.e. precipitation in excess of 21 mm per week was discounted as runoff.

The relation (equation 1) may be expanded to include the effect of drainage on the changes in water-table depth. Weekly changes in water-table depth are related to evapotranspiration, precipitation and to initial water-table depth by regression in the form -

\[ W1 - W0 = a + b1W0 + b2(E-P) \quad (2) \]

where -

- \( a, b1, b2 \) are the regression constant and coefficients and \( a + b1W0 \) represents the drainage component of the change in water-table depth.

The parameters of the regression are given in Table 6.4 for a moderately well-drained soil and also for the drumlin data re-analysed in the same way. The results show that the rate of drainage increases in both soils as the water-table rises. In the moderately well-drained soil the drainage rate increases from 18 mm per day when the depth to the water-table is 300mm to 38mm per day when the depth is 100mm. In the drumlinsoil the rates are lower, 3 and 18 mm respectively. The depth at which zero-drainage rate occurs is 477 mm and 355mm in the moderately well-drained and drumlin soils respectively. The fractional pore volume of the soils is given by the inverse of \( b2 \). The values are 0.10 and 0.29 for the moderately well-drained and drumlin soils respectively. These are reasonable values for loamy sand and clay soils respectively.
Table 6.4: Parameters of regression of change in depth to water-table (mm) on initial depth and difference between evapotranspiration and precipitation

<table>
<thead>
<tr>
<th>Soil</th>
<th>a</th>
<th>b1</th>
<th>b2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moderately well-drained</td>
<td>48.98</td>
<td>-.1026</td>
<td>9.5358</td>
</tr>
<tr>
<td>Drumlin</td>
<td>24.62</td>
<td>-.0693</td>
<td>3.4005</td>
</tr>
</tbody>
</table>

6.7 MANAGEMENT STRATEGY AND TACTICS

The two important strategic implications to be drawn from the analysis are that the stocking targets on wet drumlin soils are significantly less than those which have been established for well-drained soils and second that the conventional approach to paddock management for grazing and silage is not possible on the drumlin soils.

Accumulated experience over many years has shown that, on well-drained soil under Irish climatic conditions, a stocking target of 2.5 cows per hectare is appropriate when nitrogen use is c. 240kg/ha annually (Gately et al., 1984). These targets apply when the annual input of concentrates is limited to about 500kg/cow. Under the same conditions, on drumlin type soil the achievable targets are c.30% less. After the nitrogen strategy has been fully exploited, on drumlin type soil further advances in farm output must depend on increased farm area.

6.8 FEED BUDGETING

The primary objective of grassland management is to utilize all of the herbage efficiently. This is achieved by feed budgeting i.e. by adjustment of the areas for grazing or silage through the season. The objective of the linear programming (Tables 6.2 and 6.3) was to show the broad pattern. In normal soils ("well-drained", Tables 6.2 and 6.3), although the pattern changes from year to year, the broad pattern of a decreasing silage area occurs in all years as the rate of herbage growth decreases. In the drumlin soil this pattern is reversed. But this average pattern for the drumlin soil masks wide variation that occurs between years as a result of variation in the water-table trends. In 1984, a dry year, the conventional "well-drained" pattern of land use was possible but the other years between 1982 and 1986 showed considerable variation.

This variability, which is weather related, imposes the need for the adoption of a flexible system of grassland management. The system practised in the Netherlands provides a suitable model. There, the primary criterion for grassland use is the demand by the grazing herd. Silage is accumulated during the season as opportunity arises. The secondary status of silage does not imply that the total annual silage will be less than the amount required. Year to year variation in total annual growth on drumlin soils is not greater than elsewhere. It is the seasonal pattern of distribution of growth that varies. If the stocking level is adjusted to the appropriate target than silage recovery will be adequate.
6.9 TRAFFICABILITY

For the efficient utilization of herbage it should be grazed within 3 weeks since the previous grazing. In the case of silage, it should be harvested before ear emergence is complete at the first cut and within 6 weeks since the previous harvest for later cuts. Flexibility in the scheduling of harvest by grazing or cutting is limited by these restrictions. Therefore, the restriction of access to land by raised water-table has serious implications for system efficiency. The development of low ground-pressure vehicles is important. These vehicles not only make it possible to harvest silage on schedule but they also make it possible to feed cut herbage directly to housed stock in periods when grazing is not possible. There are some years when the drumlin soils are not trafficable by animals or conventional vehicles due to high water-tables for most of the normal grazing season. In occasional dry years they are trafficable during most of the season. In all years there are shifts from the trafficable to the untrafficable state intermittently.

In the implementation of the general strategy outlined above the day-to-day tactical decisions depend on the state of the ground i.e. on the water-table depth. The relation given in equation 1 provides a simple basis for monitoring and, with weather forecasts, for anticipating changes in water-table depth. The provision of a routine water-table monitoring and forecast service using this relation, would ease the burden of decision-making on these difficult soils.
CHAPTER 7: WEATHER AND RISK IN LIVESTOCK PRODUCTION

7.1 SUMMARY

The climate of region is defined in terms of the long-term (30 years) averages of weather. As such, climate is important in determining the broad strategic management of agricultural systems. It is not relevant to the problem of day-to-day tactical farm management. It is the variable weather, which is an important characteristic of a climate, that influences the day-to-day tactical management of farms. Variable weather is the aspect of climate that is discussed in this chapter. The discussion is focused on grassland farming in temperate climatic conditions.

7.2 INTRODUCTION

Agricultural production is closely related to weather conditions and unpredictable variation in weather is a major risk factor. The management of risk is an element in every human enterprise but in agricultural production systems the risk element is particularly important because the risk is hardly predictable, it is not in any way controllable and the effects are often great.

7.3 WEATHER AND RISK MANAGEMENT

Meteorological services have made significant progress in the accuracy of weather forecasts but this progress is limited to short-term (2-day) forecasts. There are some farm activities, such as crop spraying, that benefit considerably from the improved accuracy of short-term forecasts but in general agricultural production remains subject to wide variation that cannot be anticipated. An illustration of the scale of variation is provided by the data in Table 7.1. In the 13 years from 1982 to 1994 herbage production (dry matter), measured using the same crop every year and without variation in management, varied from 10.9 to 18.4 tonnes ha\(^{-1}\). Even when the extremely productive year, 1988, is excluded the range of production was still great.

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Prod (t ha(^{-1}))</td>
<td>11.4</td>
<td>14.1</td>
<td>12.2</td>
<td>13.1</td>
<td>13.1</td>
<td>14.1</td>
<td>18.1</td>
<td>12.1</td>
<td>12.2</td>
<td>10.1</td>
<td>13.1</td>
<td>12.1</td>
<td>12.1</td>
</tr>
</tbody>
</table>

7.4 THE COST OF WEATHER VARIATION

In the temperate climate zone, production from livestock is often based on systems where grass produced on the farm is the main source of feed. The animals spend much of the year grazing outdoors. These systems are immediately affected by weather as it affects the supply of feed and the physical environment of the grazing animal. This is in contrast to the systems of livestock production where animals are housed and where much of the feed is purchased from outside the farm. The supply in the latter case is effectively guaranteed and independent of the vagaries of weather. The sensitivity of the outdoor systems of livestock production
to weather variation is illustrated by the year-to-year variation in the use of purchased feed in response to year-to-year variation in grass growth (Table 7.2). The data in Table 7.2 show that in the two 12-month periods from July in 1985-6 and 1986-7, when the estimated production of grass was less than in the preceding or following 12-month periods, there was a reciprocal increase in the consumption of non-grass purchased. The increase in purchased feed in each of the two periods was approximately 170,000 tonnes. The financial cost of this quantity of feed would be greater than £10 million.

These data illustrate the expected response at farm level to a deficit in grass supply. The years 1985 and 1986 were years of high rainfall and it is probably that part of the increase in purchased feed was a response to the difficulty of harvesting grass by cutting or grazing under wet conditions.

<table>
<thead>
<tr>
<th>Year</th>
<th>Grass</th>
<th>Non-grass</th>
</tr>
</thead>
<tbody>
<tr>
<td>1983-4</td>
<td>25.01</td>
<td>1.01</td>
</tr>
<tr>
<td>1984-5</td>
<td>25.87</td>
<td>1.11</td>
</tr>
<tr>
<td>1985-6</td>
<td>23.92</td>
<td>1.27</td>
</tr>
<tr>
<td>1986-7</td>
<td>24.73</td>
<td>1.29</td>
</tr>
<tr>
<td>1987-8</td>
<td>29.28</td>
<td>1.09</td>
</tr>
<tr>
<td>1988-9</td>
<td>27.49</td>
<td>1.11</td>
</tr>
</tbody>
</table>

7.5 MANAGING THE WEATHER RISK

The pattern of seasonal production is predictable in broad terms as a function of the changing weather from season to season within each year and grazing systems are assembled accordingly. The basic objective of systems is to achieve high utilisation efficiency by maintaining a balance between herbage availability and herbage demand. The balance is usually achieved by adjusting the size of the grazing area progressively during the year in line with the progressive changes in herbage growth rate. The scheme of adjustment of the proportion of land allocated to grazing or silage is based on a notional "normal" pattern of weather during the year. But even in "normal" years, when total herbage production is near the expected average, the supply of herbage can alternate between surplus and deficit several times during the year.

The management of these short-term variations in growth calls for considerable skill (Brereton, 1987). The efficiency of a grass-based livestock production systems depends on the maintenance of a critical balance between herbage demand and supply throughout the grazing season. If the supply is allowed to exceed demand, herbage is under-utilised, herbage quality deteriorates and subsequent animal performance suffers. Where herbage supply falls short of demand, animal performance is reduced and overgrazing can result in thinning of the sward and reduction in herbage growth rate. There is a variety of options available to the grassland farmer to make the adjustments to the system that are necessary
to maintain an optimum sward-animal balance as the supply of herbage varies. For example, where herbage is surplus to requirements part of the grazing systems can be withdrawn temporarily and the herbage saved as silage. In paddock-grazing systems, in some circumstances, the grazing cycle can be extended, effectively storing grass in the field as a standing crop. In periods of herbage deficit an obvious option is to feed saved silage. The cycle can be shortened within limits temporarily.

7.6 NOT A CASE OF CRISIS MANAGEMENT

Computer simulation can be used to show that weather-induced fluctuations in herbage growth do not call for "crisis-management" (Brereton and Dillon, 1994 - See Chapter 9). In a simulation of a rotational grazing system for the June-October period, the effect of a reduction of 75% in herbage growth rate during August (simulated late summer drought) did not affect the operation of the system critically until one month later. The effect was to bring forward the date when silage supplementation was required from late October to late September. The effect of the simulated drought was significant. However, the exercise demonstrated that a perturbation of the normal growth pattern has a delayed effect so that a rational management response can be planned.

7.7 PRACTICAL DIFFICULTY

Although the manager has the means and ample opportunity to put tactical responses to weather changes in place it can, nevertheless, be difficult in practise to achieve an optimum response. One aspect of the difficulty is illustrated by examining corresponding changes in herbage growth and grazing cycle length. In a rotational grazing system where each paddock is grazed equally efficiently (all grazed to the same residual height for example) any variation in herbage growth rates will be reflected in corresponding variation in the herd residence time on each paddock. This in turn will affect the time taken to complete the grazing cycle of all the paddocks. An increase or decrease in the length of the cycle will occur in response to an increase or decrease in herbage growth rates. The effect on the length of the cycle will be delayed because grazing does not coincide with growth but follows after growth has taken place. For this reason the system response to growth perturbation is delayed as much as one month.

7.8 FEED-BUDGETING

It is not uncommon to find that when current growth is greater than demand that current cycle length is decreasing due to an earlier period of poor growth and that in the following period when growth rates return to lower levels that the situation is reversed. In such a situation a managers assessment of the state of the grazing system has to reconcile the conflicting indications provided by the sward and the paddock system. This may explain why, in farm practice, the utilisation of grazed grass is often less than potential. It is probable that because of these difficulties farmers tend to reduce their dependence on grazed grass by using purchased feed. They may also use greater than recommended nitrogen fertiliser as an insurance against grass deficits. Both strategies are inefficient economically and environmentally. They are risk-avoidance strategies that suggest that farmers have an exaggerated perception of risk.
It is evident that some form of feed budgeting procedure (risk management rather than risk-avoidance) is needed.

It is not surprising that the advent of personal computers has resulted in the development of feed-budgeting programmes. In New Zealand, for example, simple simulation procedures have been developed that make it possible for farmers to generate monthly feed budgets in advance (Anonymous, 1992). The budget provides relatively accurate estimates of the expected balance between herbage growth and demand so that inefficient management responses can be avoided. The procedures make use of published regional grass growth data but otherwise depend on data generated by observation within the individual farm. It is likely that such facilities will be more commonly used in the future - perhaps initially on behalf of client farmers by advisory officers.

7.9 A CASE OF HISTORY

The difficulty of managing a fluctuating herbage supply and how the difficulty may be aggravated by local farm constraints in a real farm situation is demonstrated by the following summary of experience on a wet farm in the West of Ireland in the Spring of 1990. At the start of grazing in April the allocation of land to grazing and silage was based on a norm established by experience. There were three land types on the farm - drained flat land, undrained flat land and dry slopes. In the allocation of land to grazing or silage the drained flat area was considered most suitable for silage cutting. The remaining land was grazed in the sequence - dry slopes, flat drained land and finally the undrained land. The objectives of this scheme were a) to minimise the risk of poaching damage in early Spring by grazing the drier areas first and b) to optimise the prospects of a satisfactory first cut of silage by locating the silage on drained flat land.

In 1990 grazing commenced in early April on the dry slopes. Weather conditions deteriorated and the herd was re-housed for 10 days. At the second turnout in mid-April the planned scheme was followed and grazing continued on the flat dry area and subsequently on the flat undrained area. After the second turnout herbage growth was greater than normal. It became progressively more difficult to utilise the resulting growth because of stem development. By the end of May, when the flat undrained area was being grazed, on almost all of the grazed area of the farm the herbage was stemmy, unpalatable and under-grazed. The problem of excess herbage began to become apparent in the weeks following the second turnout but the full scale of the problem did not appear until May when the herd was grazing the final set of undrained paddocks. At that stage no adjustment of the system was possible. The appropriate response to surplus herbage is to withdraw paddocks from the grazing area to be cut as silage. But when the problem was fully appreciated the only part of the grazing system where silage cutting was feasible, the flat drained area, had already been grazed.

The problem could have been solved by reducing the grazed area by withdrawing some of the flat drained paddocks immediately after the second turnout. However, the problem was not apparent then. Furthermore, there was a surplus store of silage on the farm from the previous season so that there was no incentive for management to seek to accumulate the excess herbage in the grazing area as silage. So the managers perception of the state of the system was influenced
not only by the current grazing situation but also by farm feed budget of the following Winter. It cannot be said in this difficult case that the manager made a mistake. The problem was outside his control with the resources available to him. However, if his perception of the progress of the system was supported by a forward feed-budgeting procedure, with a stochastic element in it, the manager would at least have been forewarned of the possibility and perhaps even the probability of the outcome.

7.10 CONCLUDING REMARKS

Weather variation is a major factor in the management of livestock production systems. The problems that arise for management are soluble. However, the successful manager needs to have considerable expertise and an ability to simulate the operation of the system in order to optimise management responses to weather.
CHAPTER 8: THE ROLE OF MODELLING IN GRASSLAND FARMING

8.1 SUMMARY

Technological advance and socio-economic changes in agriculture have resulted in the need for model-based decision-making aids at farm level. Models provide a means of optimising farm operations within the limits imposed by weather, soil and socio-economic factors. Ideally the farmer's decisions should be compatible with the circumstances unique to his own farm. Some examples are given of the scale of variability that occurs on farms due to local soil conditions and that occurs between years due to weather variations.

8.2 INTRODUCTION

Modelling is an essential and everyday part of scientific inquiry - though commonly it is not formally recognised as modelling unless the system under study becomes complex or unless the more sophisticated mathematical or computer techniques are used. Modelling is a technique for describing relationships between causes and effects. It is used to test our understanding of these relationships. It is a technique that imposes discipline on us - we are required to be precise in our observations and to identify clearly all of the assumptions that we make about the way systems operate. But apart from its use as a research tool modelling also has a potential role on the farm as a means of optimising the farmer's decision making process.

Farm performance generally falls short of the potential demonstrated by research. At the outset the assumption is made that the farmer making decisions objectively, using a model based system, will be better off in some way compared to his neighbour using a system based on optimistic guess work. At the same time, although an optimal system of management is by definition, better - it is recognised that the definition of 'optimal' has probably a lot to do with the personal idiosyncrasies of the farmer.

8.3 TECHNOLOGICAL PROGRESS

The relative allocation of financial resources to advice and research in agriculture has changed as the agricultural community has become more advanced technologically. In Northern Europe the fraction of total state support for agricultural development that is devoted to advisory services has declined significantly (Cunningham, 1988). This pattern is explained partly by the decline in the number of farmers. But there has been a dramatic increase in the technical awareness of the remaining farmers and the demand for new information by the industry may be expected to increase (Frawley and Commins, 1996). One of the implications of this trend is that as the farmer becomes more sophisticated technologically then he can access the result of research directly.

8.4 EACH FARM IS UNIQUE

But the farmer is a generalist whereas the researcher is usually a specialist. A direct interaction is likely to be most fruitful if the researcher has the capacity to generalise his information so that its implementation in the specific circumstances of individual farms becomes possible. A well-researched relationship - for example, the herbage response to nitrogen - is applicable in precise quantitative terms only
under the circumstances of site and weather in which the research was carried out. To a greater or lesser extent it is only semi-quantitatively or even only qualitatively applicable on individual farms. It is in this context that modelling has an important role to play.

In Ireland, it is well-established that on well-drained mineral soils in the south, permanent pasture receiving nitrogen at the rate 250 kg ha⁻¹ annually will carry 2.45 spring-calving Friesian cows (550 kg LW) each yielding 4500 litres of milk. This output is achieved on a mainly herbage diet (with approximately 500 kg concentrate per animal). On wet soils, with the same level of nitrogen use herbage production is less by a fraction of 0.3 (Chapter 6). Not only is the basic production potential less but examination of soil trafficability problems indicate that a radically different system of pasture management is required. These two instances represent the extremes of a spectrum and we can only guess at the distribution of production potential between these extremes. Against this background of variation between farms, modelling provides a means of optimising systems in relation to local conditions.

8.5 THE METEOROLOGICAL FACTOR

When much effort has been expanded in the development of a production system broadly adapted to the needs of a geographical region, it is conceivable that the adjustment of the system to suit local circumstances within the region will be made by a sort of evolutionary process leading ultimately to a universal optimization. However, the meteorological factor is always present as a 'wild card' which hampers such an evolution. Indeed, the meteorological factor probably ensures that production systems never operate optimally. Irregular variations in weather causes farmers to adopt conservative management strategies with relatively low output targets.

Chapter 5 provides an indication of the extent to which the meteorological variable can affect systems. The efficiency of a grazing system is a measure of how much animal product is obtained from each unit of herbage produced in the system. Efficiency depends on the maintenance of a correct balance between the size of the herd and its feed supply. If there is too much herbage then the system will be inefficient a) because not all the herbage will be utilized and (b) because the animals will be feeding to appetite resulting in a poor conversion of feed to animal product. On the other hand if there is a shortage of herbage, intake will be restricted and animals on a restricted diet are also poor converters.

Sward height can be used as a simple technique to maintain high efficiency. The efficiency of animal output per unit of herbage initially available increases to a maximum when the post-grazing sward height of about 60 mm. The sward height technique provides a simple means of ensuring that swards are grazed at maximum efficiency irrespective of yearly variations in herbage production. However, the time required to graze a paddock to 60 mm can vary widely from a half-day to perhaps 5 days and as a result rotation length can vary widely. To maintain a reasonable length of rotation while grazing each paddock to 60 mm the system must be supplemented by imported feed when the rotation is running short and paddocks should be taken out of the system when the rotation is running long. Continuous management adjustments are necessary. The scale of the adjustments required
varies between years as the meteorological factor varies. Relatively simple simulation models would provide the farmer in this situation with a rational framework in which he could optimise this management response.

8.6 FLEXIBLE MANAGEMENT

The farmer controls the crop, the animal and the environmental components of the system but his actions are controlled by the weather, soil and socio-economic resources available to him. In recent years his actions are increasingly being dictated also by the reaction of society to the way he manages his system. The role of modelling of systems is to provide the farmer with a framework for making decisions that are compatible with the limits imposed by weather, soil, socio-economic and society factors.

In current circumstances in Europe the farmer operates under restrictions of product amount, under restrictions of product value and also under restrictions of input use. Under these circumstances the farmer must approach management in a holistic way. He must be aware of the way system components interact. There are probably gifted individuals who will achieve success by instinct but it is likely that the average farmer will succeed only if he has access to management packages designed to assist the decision-making process.

The future will see the development of flexible systems of management, flexible for total physical and socio-economic conditions and flexible in response to the meteorological variable. These developments will occur because the farmer is able to adopt flexible strategies to maximise efficiency. Maximum efficiency is only possible when flexible management strategies are implemented. A flexible approach to management involves a greater amount of decision-making by the farmer. The modelling approach may be used to explore the flexible strategies that may be available and to develop operational systems for use at farm level.

8.7 AVAILABILITY OF MODELS

Farming is practised for a variety of reasons, not all of which are oriented towards economic or technological efficiency. The personal idiosyncrasies of the farmer, in the end, decide what are the important decisions on individual farms. Whereas one individual may be prepared to expend considerable intellectual and physical effort in the pursuit of system efficiency another individual's ideal may be an optimization that minimises the number of decisions to be made in the operation of the system. But in general there are three levels at which modelling can play a part. At the first level it can provide a guide in the choice between the alternative possible uses of the farm between cereals, horticulture, grassland, for example. At the second level it guides the choice of the strategy to be adopted in the set-up and operations of the system. At the third level it provides a basis for tactical decisions on a day to day basis. A different model is needed at each level. Over the past 20 years or so many simple and complex models, dealing with sub-system components or whole systems have appeared in the literature (Squire and Hamer, 1990). These have each probably served a primary purpose in furthering scientific understanding of the grassland system. However, there is little evidence that models have found use as operational tools at farm level. This may be due to a variety of causes. Although a model provides a clear and precise description of the real world as the
modeller perceives it, the perception of the potential user may be quite different. Especially for the uninitiated, models are not usually produced in a 'user-friendly' format. Even the 'user-friendly' model may present difficulties if the output does not suit the users perception of his decision-making problem.

8.8 MODEL PROMOTION

It is probable that the future will see further development of computerised information systems where the appropriate packages can be made available for use by farmers. However, models must be marketed to the agricultural industry. There is a need for market research to determine the needs of the industry - in terms of the components of systems that are relevant and of the desirable operational characteristics of the package.
CHAPTER 9: USE OF DYNAMIC SIMULATION FOR FEED-BUDGETING ON GRASSLAND FARMS

9.1 SUMMARY

A grazing management simulator is described. The results of a test using data from grazing experiments are used to demonstrate that the simulator is accurate. The simulator is used to show that weather-induced fluctuations in herbage growth do not call for "crises management".

9.2 INTRODUCTION

In the temperate oceanic region of Western Europe grazed grass can be the major component of the annual diet of livestock. In farm practice the utilisation of grazed grass is often significantly less than potential. Because of unpredictable variations in grass growth farmers tend to reduce their dependence on grazed grass by using purchased feed. They may also use greater than recommended nitrogen fertiliser as an insurance against grass deficits. Both strategies are inefficient economically and environmentally. These are risk-avoidance strategies. Grassland management studies at research farms suggest that these strategies are unnecessary and that the farmers have an exaggerated perception of the risk.

In New Zealand, simple simulation procedures have been developed that make it possible for farmers to generate monthly feed budgets in advance (Holmes and McMillan, 1982). The budget provides relatively accurate estimates of the balance between herbage growth and demand so that inefficient management responses can be avoided. The procedures make use of published regional grass growth data but otherwise depend on data generated by observation within the individual farm. This chapter describes a computer simulation model of grassland management, based on the New Zealand approach, which makes it possible to carry out an advance feed budget for periods of 6 months. The results are presented of a test of the model by comparison with field trials. The model is also used to show that "crisis management" is not needed when growth of herbage deviates from normal expected rates.

9.3 METHODS

The model simulates the progress of a herd of cows through a rotational paddock grazing system. The user provides initial herbage yields on individual paddocks and, for each 10-day period of the simulation, expected herbage growth rates and individual animal demand of herbage, silage or meals. Daily growth rates are calculated by interpolation between periods. The user also provides basic farm data such as herd size, paddock areas and the planned use of paddocks for silage. The time-step is 0.1 Days. The herd residence time on each of the grazing paddocks is controlled by the iterative removal of herbage in fractions equal to 0.1 of the daily feed demand until remaining herbage is less than this fraction. Rotation length is controlled by the residence time on individual paddocks and the number of paddocks allocated to grazing. Regrowth is assumed to be sigmoidal and for individual paddocks the expected growth rates are adjusted for the number of days since grazing using a function based on the logistic curve.

By adjusting the data supplied to the model the user can explore the effect of varying the parameters of herbage supply (initial herbage yields, herbage growth
rates, area withdrawn for silage) or demand (level of animal feeding) on rotation length and consequently on the production and use of herbage and on the demand for supplements.

9.4 RESULTS

Data of a rotational grazing experiment with cows were used to test the model. Between June and December cows were grazed rotationally at a stocking rate of 2.85 cows ha⁻¹ in two farmlets. In one farmlet (treatment 1) 0.35 of the farm was closed for silage until early August. In the second farmlet (treatment 2) 0.25 was closed. After the silage cut in August all of both farmlets were grazed. In both treatments supplementation with silage was introduced only when the rotation length was less than 21 days. The purpose of the experiment was to examine the effect of varying the area for grazing in June/July on rotation length and on herbage production and utilisation in late-season. The parameters of the model were adjusted to provide an accurate simulation of treatment 1. The model was tested by examining its ability to predict the effects on the system of reducing the area of silage. The model predicted the change in the pattern of rotation and the date and rate at which supplementation was introduced with acceptable accuracy (Table 9.1a and Table 9.1b).

| Table 9.1a : Duration of rotation (days). Model and experimental* data compared |
|---------------------|-----|-----|-----|-----|-----|
| Treatment | 1   | 2   | 3   | 4   | 5   |
| T1       | 22  | 21  | 34  | 22  | 22  |
| M1       | 19  | 19  | 39  | 28  | 20  |
| T2       | 33  | 50  | 41  |     |     |
| M2       | 27  | 57  | 41  |     |     |

| Table 9.1b : Date of start of silage supplementation and initial rate (dm, kg cow⁻¹ day⁻¹). Model and experimental* data compared |
|----------------|-----------------|----------------|
| Treatment | Start of Silage Feeding | Rate of Silage Feeding |
| T1       | 23/10           | 3.5            |
| M1       | 19/10           | 3              |
| T2       | 13/11           | 4.4            |
| M2       | 8/11            | 3              |

* T1, T2 = treatments 1 and 2; M1, M2 = model simulations

The effects of an unexpected temporary reduction in growth on the system represented by treatment 1 is illustrated in Table 9.2. To simulate moderate temporary drought the growth rates during mid- and late-August (rotation 3) were reduced to 0.9 (Treatment A) and 0.75 (Treatment B) of expected rates respectively. As a result the average yield of herbage during August was reduced and rotation 3 was reduced by 12 days. Silage supplement was brought forward by 1 month.
The main feature of the data is that the management response to the growth reduction in August was not required until 1 month later.

9.5 DISCUSSION

The data show that relatively simple procedures are adequate for realistic simulation of grassland management. The model is not an expert system. It provides only a description of system operation as a function of the management parameters supplied by the user. The interpretation of the output and the selection of inputs for optimal performance requires a relatively expert understanding of the way grazing systems function. For this reason it is more suited for use on farms by advisory/consultancy staff. The demonstration that perturbations in the normal pattern of herbage production have a delayed effect so that a rational management response can be planned illustrates that the model has potential for use in the context of farmer education programmes.

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<th>Rate of Silage Feeding</th>
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CHAPTER 10: DISCUSSION

The distinguishing characteristic of the livestock systems that are the subject of this report is that they are systems designed to maintain the level of animal production where the supply of feed is subject to wide variation. Variation in pasture supply is not in itself unmanageable. Throughout the temperate regions, systems of livestock production have been developed where seasonal variations in pasture supply are managed by making reciprocal seasonal adjustments in the demand for feed. In many regions these adjustments are accompanied by systems of harvesting and saving pasture during periods of the season when pasture supply exceeds demand to be fed in following periods of feed deficit.

Systems can accommodate variation in pasture supply as long as it follows a predictable seasonal pattern. Indeed, the systems are specifically designed for this. Different systems are in place in intensively farmed lowland and in extensively farmed uplands or in rangelands. These represent strategic management adjustments to climate and economic forces. In any of these systems, when pasture supply departs significantly from the normal seasonal pattern, it becomes necessary to make tactical management adjustments to minimise the effects on the livestock. It is in relation to these tactical responses to departures from normal, which are most commonly due to meteorological factors, that the agrometeorology requirement arises.

Although the maintenance of balance between feed supply and demand is primary in livestock production, the value of the relevant agrometeorological explanation may be limited where the individual farmer is concerned. Generally, departures from normal cannot be forecast. The tactical response adopted at farm level is not influenced entirely by agrometeorological considerations. This applies more particularly to farmers operating intensive systems of milk production for example, where the pasture is continuously monitored so that the state of the production system is substantially known. However, for extensive producers, and at regional, national or even continental levels of administration the agrometeorological information may be of critical value.

Secondary, though not less important, elements of livestock production systems are the

- Management of animal health and reproduction
- Management of land trafficability for machinery and livestock
- Management of forage for mechanical harvest,
- Pasture disease management,
- Management of the atmospheric, ground water and wildlife environment in relation to disposal of animal wastes, application of fertiliser, and grazing and forage harvesting.

It is in relation to these secondary elements that agrometeorological information has the most obvious role to play. In many cases short-term agrometeorological forecasts are required. Warnings based on forecasts with a lead-time of hours are relevant to silage wilting decisions and animal waste disposal activities. In other cases historical weather records can be used to assess disease risk (liver fluke). Combined historical rain data and short-term rain forecasts can be used to assess risk of land damage due to wheeled or animal traffic.
It is evident that the management of the balance between feed supply and demand in livestock systems and the management of pasture utilisation, animal health and the environment is significantly affected by the meteorological elements such as temperature, radiation precipitation, etc. However, the meteorological data itself usually has no agrometeorological value. The interpretation of the meteorological elements in the agrometeorological context is often complex. For example, in the assessment of heat stress or cold stress in livestock, the critical temperature varies according to humidity, wind and precipitation. Similarly, the forecast of soil trafficability requires an evaluation of previous rainfall and evaporation as well as data on forecast rainfall. Because of the complexity of interpretation required, agrometeorological information must be defined in terms of models. National Meteorological services do not generally devote substantial resources to the translation of meteorological data to the agrometeorologically useful information required by agriculture. For this reason it is probable that the agrometeorological requirements of pasture-based livestock producers, along with agricultural producers generally must depend on other agencies.

Every agrometeorological relation that is understood has a potential application in farming. Unlike the other production factors such as fertilizer, irrigation, genetics etc. the agrometeorological relations are always associated with risk - not controlled by the farmer. The farmer can only manage the effect, not the cause. In the non-agrometeorological case management is the cause and management is concerned with producing an effect. The culture of modern grassland farming tends to accept the meteorological factor as a risk with the same status as the demands in everyday life that are the currency of the insurance actuary. For this reason, the value of agrometeorological information and its application has to be assessed on a different basis. It’s value is related to the degree of certainty associated with the information. Agrometeorological information has greatest practical value when it tells the 'now' situation. Local short-term precipitation forecasts based on radar have high value. In a sense long-term averages for a region are 'now' forecasts and have high value for strategic management planning decisions. However, in a general way the value of agrometeorological information for tactical planning decreases rapidly as the period (days) of forecast increases. This is because the accuracy of forecasts decreases rapidly when the period of the forecast is greater than c.48 hours. Because of the uncertainty the user accepts the meteorological forecasts passively and for this reason decision responses are not made.

To increase the value and effectiveness of agrometeorological data it is necessary to develop forecasting procedures that include an estimate of the probability of an outcome. Furthermore, it is not sufficient to provide farmers with the basic meteorological elements. Farmers are not meteorologists and it is necessary that the data be presented to the user in the form that is readily interpreted in agricultural terms. In many cases, even then, it is not sufficient to provide information on the short-term expectation. In itself, a prediction of water stress is meaningless unless it is related to the existing state of the system resulting from previous meteorological conditions.

The circumstances of individual farms and farmers, even within small areas, are very heterogeneous. Tactical management is a complex activity dictated by the separate demands of land, crop, livestock and environmental management. The meteorological services need to produce output that integrates the meteorological
elements and the elements of the complex systems that are farming, that relate meaningfully to the demands of tactical management. The survey shows clearly that this is not generally available at present. The future of livestock producers in temperate regions holds the prospect of reduced profit margins. There is a growing awareness of the danger of rural depopulation. For economic and social reasons therefore, it is important to reduce the risk element in livestock farming and to increase the security of the producers.

In the past, it was considered appropriate that government agencies should provide the type of service that is urged here. However, in recent years governments have tended to unload responsibility for such services on to the private sector. Therefore, it is from this sector that in future the necessary services will come. However, the World Meteorological Organisation should recognise the need and begin to foster the development of the necessary agrometeorological modules. The many reports already published by the Organisation in the Technical Note series and in the Agricultural Meteorology C.Ag.M Reports series, this series provide evidence of the wealth of information that is available for the purpose.
APPENDIX: INTERNATIONAL SURVEY OF AGROMETEOROLOGICAL SERVICES TO LIVESTOCK PRODUCTION IN TEMPERATE CLIMATE REGIONS

An international survey was conducted with the objective of determining the range of agrometeorological services provided to the livestock producer in relation to the size of the industry in each country. The questionnaire that was issued to each country was designed to obtain information on the scale of the livestock industry and its social significance in terms of the numbers is engaged directly and in directly in the livestock production industry. But the primary objectives were to determine what type of agrometeorological information was provided to the industry. Thirty countries responded to the survey. Of these, 14 had livestock producers operating in temperate climate regions. In all of them the weather forecasting/warning systems available to the general public are also available to agriculture. Agricultural weather forecasts are provided in only 4 of the countries. In these the forecast interpretation in terms of tactical response actions is largely left to the farmer. More active participation by the meteorological services is represented by warnings. These are provided in only 5 countries and not all the same countries as before. The most active participation by meteorological services is where the services use agrometeorological models to simulate and anticipate the biological response expected at farm level. In this case only 5 countries provided services. There was no consistency between the countries that actively provided an agricultural service in the way the various communications media were utilized. Overall the survey indicated that the agrometeorological services have developed in an ad hoc way with no underlying concept of a comprehensive and evolving structure.
REFERENCES:


