AGRICULTURAL METEOROLOGY

CAGM REPORT NO. 35

Part I: Survey of the Operational Methods in use for Agrometeorological Services for Potato Crop Production

Part II: A: Study on Requirements to be met by an Agrometeorological Service in Countries with Highly Developed Industries

B: Requirements in Agricultural Meteorology in the Highly Industrialized Areas with Developed Agriculture

Part III: Agrometeorological Data Bank

Part IV: A: Influence du temps et du climat sur la qualité des recoltes

B: Information on the Study of Weather and Climatic Impacts on the Quality of Grain Crops

(Report prepared by the RA VI Working Group on Agricultural Meteorology
Chairman: Mr. J. Hrbek)

WMO/TD-No. 381

Geneva, 1990
"This report has been produced without editorial revision by the WMO Secretariat. It is not an official WMO publication and its distribution in this form does not imply endorsement by the Organization of the ideas expressed."
Part I: Survey of the Operational Methods in use for Agrometeorological Services for Potato Crop Production

Part II: A: Study on Requirements to be met by an Agrometeorological Service in Countries with Highly Developed Industries
             B: Requirements in Agricultural Meteorology in the Highly Industrialized Areas with Developed Agriculture

Part III: Agrometeorological Data Bank

Part IV: A: Influence du temps et du climat sur la qualité des recoltes
             B: Information on the Study of Weather and Climatic Impacts on the Quality of Grain Crops

(Report prepared by the RA VI Working Group on Agricultural Meteorology
Chairman: Mr. J. Hrbek)
NOTE: Part IIA not included

- will be published separately
# CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>List of Tables</td>
<td>1</td>
</tr>
<tr>
<td>List of Figures</td>
<td>iii</td>
</tr>
<tr>
<td>Introduction</td>
<td>i</td>
</tr>
<tr>
<td>Layout of the Report</td>
<td>1</td>
</tr>
<tr>
<td><strong>Part A - Agrometeorological services for potato crop production</strong></td>
<td></td>
</tr>
<tr>
<td>1. Introduction</td>
<td>3</td>
</tr>
<tr>
<td>2. Analysis of the questionnaires</td>
<td>6</td>
</tr>
<tr>
<td>2.1 Preplanting</td>
<td>6</td>
</tr>
<tr>
<td>2.2 Planting time</td>
<td>9</td>
</tr>
<tr>
<td>2.3 Growing season</td>
<td>11</td>
</tr>
<tr>
<td>2.4 Harvest</td>
<td>19</td>
</tr>
<tr>
<td>2.5 Storage and Transport</td>
<td>19</td>
</tr>
<tr>
<td><strong>Part B - Agrometeorological methods for potato crop production</strong></td>
<td></td>
</tr>
<tr>
<td>1. Preplanting</td>
<td>32</td>
</tr>
<tr>
<td>1.1 Physiological age</td>
<td>32</td>
</tr>
<tr>
<td>2. Planting</td>
<td>34</td>
</tr>
<tr>
<td>2.1 Soil temperature</td>
<td>34</td>
</tr>
<tr>
<td>2.1.1 Estimating daily maximum and minimum temperatures at 10 and 30 cm depths</td>
<td>34</td>
</tr>
<tr>
<td>2.1.2 Estimating daily maximum and minimum 10 cm soil temperatures from standard meteorological data</td>
<td>36</td>
</tr>
<tr>
<td>2.1.3 Soil temperatures and heat flow</td>
<td>38</td>
</tr>
<tr>
<td>2.1.4 Prediction of soil temperature</td>
<td>39</td>
</tr>
<tr>
<td>3. Growing season</td>
<td>41</td>
</tr>
<tr>
<td>3.1 Modelling of growth and development of potato</td>
<td>41</td>
</tr>
</tbody>
</table>
3.1.1 Static models
(a) Temperature and weather-yield relationships
(b) Light interception models
(c) Crop growth rate and effective length of the growth period
(d) Transpiration efficiency

3.1.2 Dynamic simulation models
3.1.2.1 Simple dynamic models
(a) Wageningen methods
   (i) Agro-ecological zone method
   (ii) Linear growth model
   (iii) Summary model: SUCROS
(b) A simple model of potato growth and yield
(c) Simulation model of potato growth and development
(d) Crop production potentials
(e) Pocket calculator model for potatoes

3.1.2.2 Comprehensive dynamic simulation models
(a) Physical crop production model
(b) BACROS
(c) The POTATO model
(d) SWACRO
(e) A dynamic model of potato growth and development

3.2 Crop water requirements and irrigation
3.2.1 FAO-method
3.2.2 MORECS
3.2.3 Irriguide
### 3.2.4 Long term Irrigation Planning Programme (IPP)

- 88

### 3.2.5 Irrigation management services

- 91

### 3.2.6 Estimation of water and irrigation requirements of potato

- 93

### 3.2.7 Irrigation using pan A evaporation data

- 95

### 3.3 Forecasting systems and simulation models of pests and diseases of potato

- 96

#### 3.3.1 Simple warning systems

- 109

##### 3.3.1.1 Dutch rules

- 109

##### 3.3.1.2 Beaumont's rules

- 110

##### 3.3.1.3 Smith rules

- 110

##### 3.3.1.4 Irish rules

- 111

##### 3.3.1.5 The Norwegian rules

- 112

##### 3.3.1.6 Poland rules

- 112

##### 3.3.1.7 Finland rules

- 113

##### 3.3.1.8 SIMPHYT

- 113

##### 3.3.1.9 Hyre's system

- 114

##### 3.3.1.10 Wallin's system

- 115

##### 3.3.1.11 BLITECAST

- 117

#### 3.3.2 Negative forecasting systems

- 123

##### 3.3.2.1 PHYTPROG

- 123

##### 3.3.2.2 Negative forecasting system in Israel

- 127

#### 3.3.3 Simulation models

- 130

##### 3.3.3.1 Blight

- 130

##### 3.3.3.2 A Simulation model of Phytophthora infestans

- 137

##### 3.3.3.3 Lateblight

- 140

##### 3.3.3.4 Potato Disease Management (PDM)

- 142

#### 3.3.4 Warning Systems for other pests and diseases

- 144
3.3.4.1 Warning Systems for potato early blight  
(Alternaria Solani) .......................... 144  
(a) Growing degree-days method ............... 144  
(b) Physiological days method .................. 144  
(c) Fast model .................................. 144  
3.3.4.2 Nematode potato model .................. 146  
3.3.4.3 Forecasting of the incidence of potato  
aphids in Scotland ............................ 149  
3.4 Spraying forecasts ........................... 150  
3.4.1 A simple model of spray drift ............... 150  
3.4.2 Random-walk model .......................... 152  
3.4.3 Spray-occasion criteria ..................... 154  
3.5 Frost protection methods ...................... 157  
4. Harvesting, Storage and Transport ............. 159  
4.1 Simulation of potato store temperatures ...... 159
List of Tables

1. List of National Research Institutes, engaged in potato production.
2. List of most important varieties grown in each country.
3. Agrometeorological Advisory Services for Potato Production.
4. Simple static and dynamic models which were used to analyses potato growth and yields.
5. The calculation of potential yield of potato.
6. (a) Crop coefficients ($K_c$) for use with grass reference ETo and yield response factors ($Ky$).
      (b) Basal evapotranspiration crop coefficients ($K_{cb}$) for use with alfalfa.
      (c) Soil depletion factor ($p$) for potato as a function of crop evapotranspiration.
7. Potato late blight warning systems
      (a) Warning Systems based on several weather criteria
      (b) Negative Forecasting Systems
      (c) Warning Systems based on simulation models
8. Warning Systems for other pests and diseases
      (a) Early Potato Blight (Alternaria Solani)
      (b) Other pests and diseases
9. Relationship of temperature and relative humidity periods as used in the Wallin blight forecasting system.
10. Adjustable matrix to relate 'severity values' (Wallin's system) and rain favourable days (Hyre's system) and generate spray recommendations for Blitecast.
11. Blight units as determined by cultivar resistance, temperature and periods of high relative humidity.
12. Fungicide units for chlorothalonil as determined by rainfall and time since last fungicide application.
13. Decision rules for the simulation forecast for potato late blight.
14. Average defoliation from late blight and average number of fungicide applications for 10 simulated seasons for spraying according to BLITECAST and at 7-day intervals.
15. Table obtained from Ullrich and Schrodter, showing the calculations of the Weekly Phytophthora Index.

17. Factors influencing the development of Phytophthora infestants and operation of the model to simulate potato blight epidemics (Lateblight model).

18. Relationship of leaf wetness period and average temperature during the wetness period to severity values using FAST model.

19. Relationship of average temperature for the past 5 days, hours of relative humidity greater than 90% for the past 5 days and total rainfall for the past 7 days to severity rating values using FAST model.

List of Figures

1. Flowchart of estimating the soil temperature.

2. Basic block diagram of a potato growth and development (Israel).

3. Scheme of the SWACRO model consisting of the water balance model SWATRE (Soil Water Actual Transpiration Extended) and the yield model CROPR (Crop Production).

4. Flow chart of the integrated SWACRO model for computing the influence of water management on yields of arable land.

5. A suggested relationship of the duration of high relative humidity periods and the average temperature during that period to the likelihood of infection and the corresponding severity value of potato late blight.

6. Relationship between temperature during the first month after planting and the age of the potato crop at blight appearance.

7. Periods for calculation of blight infections.

8. Flow chart for calculation of INFECT in the blight model.

9. Life cycle of the fungus Phytophthora infestans as represented in the model.

10. Relational diagram of growth and development of the potato plant and the cyst-nematode, Globodera pallida.
PART I : Survey of the operational methods in use for agrometeorological services for potato crop production

(Prepared by S. Pashiardis)

(The English version provided by the author is reproduced without editing)
SURVEY OF THE OPERATIONAL METHODS IN USE FOR
AGROMETEOROLOGICAL SERVICES FOR POTATO CROP PRODUCTION

Introduction

Potato is the fifth largest crop in the world in terms of energy production (Van der Zaag, 1983). It is one of the most important field crops grown in many countries of the world. It is a weather-sensitive crop and agrometeorological information can be applied profitably to many different problems of potato production. The agrometeorology of this crop has been studied in many countries, and operational agrometeorological information is available. This information can be used to improve potato production, its quality and the efficiency of its cultivation.

The Regional Association VI (Europe) on Agricultural Meteorology, recognizing the need for the development of specialized services for potato crop production, has decided to establish a Working Group with the following terms of reference:

"To survey and summarize the operational methods in use for agrometeorological services for potato crop production in a form suitable for consideration by the Member countries in the Region".

This survey is a continuation of the work prepared by the previous Working Group of the Regional Association VI (Europe), which had the responsibility to prepare a Report concerning the literature review of the agrometeorology of potato (WMO, 1988). Furthermore, a Symposium on the Agrometeorology of the potato crop was organized by WMO and other International Organizations in Wageningen (The Netherlands) in April 1987. The purposes of the Symposium were to stimulate cooperation in the application of meteorological information to potato cultivation, to improve potato production and quality, decrease the damage due to pest and diseases and increase the economic benefits of potato growing (Rijks and Stigter, 1988).

Layout of the Report

The Report is divided into two parts. The first part summarizes the answers received by the respondents to the questionnaires which were distributed to the members of the Working Group of Regional Association VI and to other researchers from National Institutes engaged in potato crop production activities.

The second part describes the methods which are in operational use by various Meteorological Services and other Institutes. Each method is described in a form almost similar
to CARS-FOOD Referral System. Information is given about the objectives of each method, form of output, description of the method, input data, operational requirements, its validity and limitations and finally any available references.

The survey is divided into six sections according to the sequence of the agricultural operations applied for potato production, i.e. preplanting, planting, growing, harvest, storage and transport.

References


PART A - AGROMETEOROLOGICAL SERVICES FOR POTATO CROP PRODUCTION

1. Introduction

The first part of the Report refers to the analysis of the questionnaires set up and distributed to the members of the Working Group of the Regional Association VI and to other researchers from National Research Institutes engaged in potato crop production activities.

The first questionnaire covered the following topics:

1. The "physiological age" of the seed tubers
   - Storage conditions of the seed tubers and necessary agrometeorological information for planning purposes and day to day operations.

2. Planting date
   - Determination of the optimum planting date through modelling or through experimentation.
   - Analysis of the environmental parameters (such as temperature) to estimate the optimum planting period.

3. Irrigation scheduling
   - Amount, frequency and time of irrigation.

4. Frost warning systems
   - Analysis of temperatures below 0 C to assess any operational method for frost protection.
   - Effectiveness of each method.

5. Warning systems for crop protection from pests and diseases
   - Models and examples should be given.

6. Modelling of growth and development of the crop
   - Objectives, model description, area and time scale, input data requirements, validation, application and limitations, computer requirements, references, contacts, any financial assistance which is required.

7. Agrometeorological information supplied to the farmers.
   - For any information supplied, please specify the followings:
     a) Form of presentation of the data,
     b) Dissemination of the agrometeorological information, telecommunication systems.

A second questionnaire was released by WMO by the end of 1988, with the aim of updating the accumulated information on the operational services to potato crop production. The questionnaire had the following form:
AGROMETEOROLOGICAL ASPECTS OF POTATO CROP PRODUCTION

Member of WMO: .................................................................

1. Please list all the National Research Institutes engaged in potato production, as well as their main research activities concerning this crop. List of National Research Institutes engaged in potato production.

<table>
<thead>
<tr>
<th>National Research Institutes</th>
<th>Address</th>
<th>Main Research Activities</th>
<th>Persons who could be contacted</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. Please provide information on the phenology and other information on the varieties of potato crops grown in your country.

<table>
<thead>
<tr>
<th>Potato Varieties</th>
<th>(a) Time of cultivation</th>
<th>(c) Total growing period (days)</th>
<th>(d) Daylength requirements</th>
<th>(e) Specific climatic constraints</th>
<th>(f) Average yield (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(a) Potato varieties: please list the most important varieties.
(b) Time of cultivation: indicate the time of the year when potatoes are grown.
(c) Total growing period: please specify the length of the growing period for each cultivar.
(d) Daylength requirements for flowering: please indicate whether the cultivar is a short or long day plant.
(e) Specific climatic constraints: please specify any climatic constraint during the growing period for each cultivar.
(f) Average yield: please give the average yield in tuber fresh weight in kg/ha.
3. Please provide operational agrometeorological services during the various cultural operations. For each method listed, please complete the attached CARS format.

Cultural operations

- Pre-planting
- Planting
- Irrigation
- Spraying
- Frost occurrence
- Harvest
- Storage
- Others

4. Has any model been developed for (a) growth and development and (b) yield of potato crop? (Yes/no)

If your answer is yes, please provide information on a separate sheet and/or attached published literature.

5. How do you ensure timely transmission of advisories and information to the end user?

The results of the answers of the respondents are analyzed in the following sections. References are given in the second part when each method is described in detail. Table 1 shows a list of the National Research Institutes engaged in potato production. Table 2 provides information about the varieties grown in each country. Finally, Table 3 summarizes the Agrometeorological Advisory Services to Potato Production, according to the answers received from the questionnaires.
2. Analysis of the questionnaires

2.1 Preplanting

United Kingdom

Physiological age: Higher yields of early potatoes come from planting seed potatoes that have already sprouted. The length of sprout depends on the physiological age, and this in turn depends on degree-days above 4 C. A scheme which assess the need for heating or cooling the storage house is available.

Contamination with Sprout Suppressant: An Agricultural Development and Advisory Service (ADAS) study was undertaken in 1987 into the levels of contamination of CIPL and TCNB from stored ware potatoes onto seed potatoes stored close to the ware. The study reveals an apparent temperature dependence (to be published).

Chilling in Transport: A forecast service is available to seed producers (primarily Scottish), to assist them in avoiding cold spells during transport of seed to English growers.

Covering Seed in Transport: An experiment was carried out by the Scottish seed producers, in conjunction with ADAS, to determine the effect on tuber temperature of different types of covering materials on lorries - results awaited.

Ireland

Physiological age: Early potato cultivars such as Homeguard and British Queens are placed in sprouting trays and houses for planting out during the period February-March. The optimum physiological age for early harvesting ranges from 400 to 600 Cd. Maincrop varieties, such as Kerrs Pink and Record, are sprouted in February for April planting giving a physiological age of 100-200 Cd.

Finland

Physiological age: After harvesting (in the middle of August) the tuber seeds are stored in store houses where a temperature of 4 C is held. Such conditions are held till February. After that time the tuber seeds are exposed to temperature of 10-12 C up to the planting time.

Poland

Physiological age: Experiments are carried-out to determine the storage conditions (temperature and light) for optimum physiological age.
Czechoslovakia

- Physiological age: The preplanting treatment of potatoes is carried out under the controled microclimate and weather does not exert any substantial influence.

German Democratic Republic

- Physiological age: List of certified varieties that may be bred, grown and marketed in the G.D.R. - Valid in 1984. Extract from the Certified Variety List.

<table>
<thead>
<tr>
<th>Ripeness group (Percentage of total crop planted)</th>
<th>Variety</th>
<th>Growing season (in days)++</th>
<th>Cultural value +</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gr. 1 - Very early time of ripeness (about 15%)</td>
<td>Astilla</td>
<td>113</td>
<td>Sp</td>
</tr>
<tr>
<td></td>
<td>Arkula</td>
<td>118</td>
<td>Sp</td>
</tr>
<tr>
<td>Gr. 2 - early time of ripeness (about 8%)</td>
<td>Karat</td>
<td>117</td>
<td>Sp</td>
</tr>
<tr>
<td></td>
<td>Lisera</td>
<td>116</td>
<td>Sp, V</td>
</tr>
<tr>
<td></td>
<td>Auralia N +</td>
<td>119</td>
<td>Sp, V</td>
</tr>
<tr>
<td></td>
<td>Dorisa</td>
<td>120</td>
<td>St, V</td>
</tr>
<tr>
<td></td>
<td>Elgina</td>
<td>123</td>
<td>St, V</td>
</tr>
<tr>
<td>Gr. 3 - medium early time of ripeness (about 60%)</td>
<td>Adretta</td>
<td>123</td>
<td>Sp, St, V</td>
</tr>
<tr>
<td></td>
<td>Koretta N +</td>
<td>124</td>
<td>Sp</td>
</tr>
<tr>
<td></td>
<td>Salut N +</td>
<td>124</td>
<td>Sp</td>
</tr>
<tr>
<td></td>
<td>Karella N +</td>
<td>127</td>
<td>Sp</td>
</tr>
<tr>
<td></td>
<td>Lipsi</td>
<td>130</td>
<td>St, V</td>
</tr>
<tr>
<td></td>
<td>Sola</td>
<td>134</td>
<td>Sp</td>
</tr>
<tr>
<td></td>
<td>Xenia N +</td>
<td>131</td>
<td>Sp</td>
</tr>
<tr>
<td></td>
<td>Galina</td>
<td>140</td>
<td>Sp, St, V</td>
</tr>
<tr>
<td>Gr. 4 - medium late time of ripeness (about 17%)</td>
<td>Libana</td>
<td>140</td>
<td>Sp</td>
</tr>
<tr>
<td></td>
<td>Mariella</td>
<td>144</td>
<td>Sp</td>
</tr>
<tr>
<td></td>
<td>Karpina</td>
<td>146</td>
<td>Sp</td>
</tr>
<tr>
<td></td>
<td>Libelle</td>
<td>143</td>
<td>Sp</td>
</tr>
<tr>
<td></td>
<td>Maxilla</td>
<td>146</td>
<td>St, V</td>
</tr>
<tr>
<td></td>
<td>Turbella</td>
<td>150</td>
<td>St, V</td>
</tr>
</tbody>
</table>

+) Meaning of the symbols:

N = nematode-resistant variety
Sp = ware potato
St = starch and fodder potato
V = suitable for breeding

++) Growing season: Mean value obtained in experiments on the duration of the growing season (from date of planting up to date at which more than 80% of the leaves are decayed)

Seed potatoes which belong to the medium ripeness group should have an average physiological age of 600 to 1000 degree-days (mean daily air temperature multiplied by the number of days).
Yugoslavia

- **Physiological age:** The agroclimatic study of potato crop is in its initial phase. The first phase concerns the spatial and temporal distribution of sprouting and blooming of the midseason varieties, such as Bintye and Desire. Using the established linear regression model, the correlation of such phases and altitude has been obtained for the homogeneous phenoclimatic areas. The vertical gradient for both phases is on average 3 days/100 m.

After establishing similar indices for the phase of physiological maturity of the mentioned midseason varieties, the same research will be carried out for the early varieties of potato such as Saskia and Mesecar.
2.2 Planting time

United Kingdom

- Soil temperatures:
  (i) Soil temperatures at 30 cm depth at 0900 GMT are available synoptically. During spring and autumn in the U.K. this approximates to the 10 cm mean daily temperature. Accordingly, advice on soil temperatures for planting and harvesting is passed to ADAS advisory staff.

  (ii) Methods are being investigated to produce a 7 day forecast of soil temperature.

  (iii) Traditionally the growing season is taken as the length of time for which soil temperature at 30 cm is above 6°C.

  (iv) The effects of ridge orientation on soil temperatures at different planting depths have been studied recently.

- Soil management: Evaporation and soil moisture status for three different soil textures are available via the weekly MORECS bulletins. The Meteorological Office Rainfall and Evaporation Calculation Scheme (MORECS) was developed to meet the needs of agriculture and the water industry for prompt, nation-wide estimates of weekly and monthly evaporation, transpiration and soil moisture deficits. The data are supplied in the form of averages over 40 X 40 km squares covering Great Britain. Evapotranspiration estimates are based not only on the meteorology, but also on crop and soil type.

- Weather forecasts: Routine forecasts for periods of between 1 and 5 days are available from various sources (radio, television and view data).

Yugoslavia

- Planting time is determined through experimentation. Because of different kind of landscape and climatic characteristics of growing sites planting time starts mainly at the beginning of April and lasts till the first days of May. Planting time is also related to the altitude.

Poland

- Optimum planting dates are determined through field experiments and through the analysis of the environmental parameters (air and soil temperatures and rainfall).

Federal Republic of Germany

- Soil temperature are estimated from a model using air temperature, sunshine duration and total solar radiation data.
Czechoslovakia

a) Agroclimatological information: Probabilities of reaching and exceeding soil temperature of 6°C at 20 cm by a given date have been calculated for some areas.

b) Meteorological information for daily operational decisions

- Short term weather forecasts, especially rainfall forecasts for 1-2 days, and weather forecasts for agriculture for 5 days are used. The pre-planting without being interrupted by rain.

- The planting date is determined by reaching of necessary soil temperature and by weather with no or little rainfall only, resulting in a good trafficability of soils.

Ireland

For unsprouted seed the guideline of 3 consecutive days of 6-7°C is sufficient to initiate sprout growth. With sprouted seed 4-5°C is sufficient for growth. Generally, the condition of soil has a major influence on the date of planting.

German Democratic Republic

Soil moisture at planting should be between 55 and 70% of the field capacity in order to obtain higher yields. Potatoes should be planted as soon as soil temperatures are above 8°C (as a rule within the first ten-day period of May).

U.S.S.R.

The crop is planted immediately after the soil temperature is reliably over 7°C, which gives good shoots if the soil has already become soft and pliable. Planting any earlier is not advisable as at soil temperatures below 7°C potato shoots may be stricken by rhizoctonia, which develops best at 4-5°C. In over moist soil (saturated to over 80% of total moisture capacity), the potato dies from lack of air. Also, machines cannot function well and the tubers cannot be tamped down properly if the soil is too damp. Lastly, the planting date must be calculated to ensure that the shoots are not nipped by frost.
2.3 Growing season

United Kingdom

- Growth and developmental models: Growth and developmental models relate the dry matter accumulation and developmental stage of the crop to the weather. The potential yield model developed by McKerron (1985) is to be programmed by the Agrometeorological Department in Bracknell, in order to test the feasibility of running such a model operationally.

- Irrigation Planning: Using data from the national rain-gauge network or rainfall data measured on particular farms, MORECS calculates "soil moisture deficit" which is used to estimate "irrigation need". Two types of information is available:

  (i) **Daily irrigation planning** advice through the ADAS/Agromet Irriguide service, and

  (ii) **Strategic (long term) irrigation planning** service is offered by a program which incorporates the grower's specified strategy with a daily moisture balance calculation. Statistics giving probabilities of the percentages of the driest years are also calculated.

- Disease indices and warning systems: Indices for potato blight are issued daily during the growing season. Smith periods and Sparks (1980) model are calculated daily. As disease development also depends on the pre-existing level of infection, the value of a disease index is greatly enhanced when combined with crop reports of the recent status of the disease. An overview of the warning system is given by Roe (1984).

- Spraying forecasts: Apart from the weather forecasts, the factors which determine spray drift have been studied by Thompson and seasonal summaries of spraying hours are available by Spackman. The potential use of specialized spraying forecasts have been examined by Douglas.

- Haulm destruction: The application of some desiccants (e.g. Reglone) are soil moisture dependent. MORECS can be used to give area values for main crop moisture deficits.

Finland

- **Irrigation need**: Soil moisture is measured at the Agricultural Research Center and accordingly the irrigation need is estimated.

- Frost warnings: Frost warnings are included in farm weather service. The following frost protection measures are used by the farmers: Irrigation, fog generation, fibermulches and air mixing using helicopters.
- Disease indices:

(i) The warning system for potato late blight is based on air temperature and relative humidity. The daily risk rate (0-4) is calculated according to the following table:

<table>
<thead>
<tr>
<th>Average temperature when RH &gt; 90%</th>
<th>Time in hours when RH &gt; 90%</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.2 - 11.6</td>
<td>15  16-18  19-21  22-24 &gt;25</td>
</tr>
<tr>
<td>11.7 - 15.0</td>
<td>12  13-15  16-18  19-21 &gt;22</td>
</tr>
<tr>
<td>15.1 - 26.6</td>
<td>9   10-12  13-15  16-18 &gt;19</td>
</tr>
</tbody>
</table>

Risk rate: 0 1 2 3 4

When the risk rate of the previous 7 days is:

- over 6, spraying is necessary during the next 5 days
- 5-6, spraying is necessary during the next 7 days
- under 4, no spraying is needed.

The blight sensitivity of the variety has to be considered when making the decision to spray.

(ii) The virus spreading warnings are based on the amount of aphids.

Yugoslavia

- Irrigation need: An amount of 30 mm/m² in 5 to 10 days is recommended, depending on the actual soil moisture.

- Disease indices:

(i) The warnings for the late potato blight are made by the Farm Institute on the basis of primary infection. The negative prognosis developed by Schrodter and Ullrich is being investigated.

(ii) The appearance of the first generation of larvae of Colorado beetle (Leptinotarsa decemlineata) is related to the average daily temperature. Warnings are issued on the basis of the mass appearance of the pest.

Poland

- Models of growth and development: Statistical models are used to determine the effect of the weather on crop growth and development.

- Irrigation need: Experiments are carried out to determine the tolerance of potato cultivars to water deficit.
Hungary

- **Modelling growth and development:** Statistical models using precipitation and sunshine duration data are examined to relate potato yield and weather.

- **Irrigation need:** The crop water requirements are estimated using average values of potential evapotranspiration and crop coefficients. The difference of the potential and actual evapotranspiration determines the irrigation requirements.

- **Weather summaries:** Agrometeorological Bulletins are issued every 10 days for the main agrometeorological stations. The Bulletins contain information of the weather of the past ten days and the expectable weather of the next ten days.

Portugal

- **Growth and development models:** The potato model developed by Ng and Loomis was improved and adapted to respond to different water regimes by P.A. Pinto at the University of California, Davis. The model was tested against an early potato crop in Portugal, with good performance.

- **Irrigation planning:** Field tests are carried out in two agroecologically different regions to collect micrometeorological data and to determine the water consumption of the potato crop.

Ireland

- **Modelling of growth and development:** The Agricultural Research Institute is testing the Mackerron (1985) model. Some modifications of the weighting and conversion factors are required.

- **Irrigation planning:** Irrigation is not very common practice under the Irish climatic conditions. However, in light soils a general guideline is to apply 25 mm of water at 25-30 mm soil moisture deficit (SMD). On medium-heavy loams the guideline is to apply 25 mm from 35-45 mm SMD.

- **Disease indices and warnings:** The Meteorological Service provides a warning service on potato blight based on the Irish (Bourke) rules. Although the system is based on a simple conditional model it has been found useful to monitor the season and identify important infection periods.

- **Advisory services:**

  (a) Weekly Tillage Crop Reports issued by the Agricultural Advisory (or Extension) Service include the state of the potato crop and recommendations for specific operations regarding growth and disease control incorporating weather summary and forecast. Issued through the national media, radio and press.
(b) The farm management section is the Irish Farms Journal includes information as in (a). Published weekly.

(c) Warnings of weather conditions conducive to the spread of potato blight are issued by the Meteorological Service as necessary through the national radio (immediate) and through (a) and (b) above.

Israel

- **Modelling growth and development:** A model for the main processes in potato growth was developed and used for the simulation of crop production under different meteorological conditions. The main control factors considered in the model are irrigation, fertilization and timing of harvest. The model is constructed on the level of plant community. The time interval for the simulation of general dynamic processes is one day. To describe some important physiological processes during a day, the simulation is performed by subroutines with hourly time steps.

- **Irrigation planning:** Experiments showed that maximum yield can be obtained when the ratio of the water applied to Class A pan evaporation (W/Ep) was equal to 0.91 and 1.04 for drip and sprinkler irrigation, respectively.

- **Disease indices:**
  (i) **Negative disease forecasts** are practised to predict the disease-free periods. Such forecasts, based on an empirical relationship of temperature and the disease-free period, provide economically important information for the timing of control operations and may avoid unnecessary applications of pesticides.

  (ii) **Experimental results** showed that the time of irrigation affects the rate of blight development. Morning irrigations increase the rate of blight development than those in the evening.

- **Weather Summaries:** Agrometeorological Bulletins for each 10-day period are issued by the Agrometeorological unit.

Czechoslovakia

a) **Agroclimatological information**

- For potato growing crop-rotation with green manure is partly used. Consequently the studies of how the climate answers to the requirements of the catch crops and under crops and the delimitation of zones with rainfall and temperatures convenient for the growing of green manure crops is of interest.
b) Meteorological information for daily operational decision

- Routine regional short term weather forecasts, especially the rainfall forecasts are used for the soil cultivation in the early spring.

- During the whole vegetation period the routine weather forecasts for agriculture, covering a period of 5 days, are used for the weekly planning of field operations. This plan is further developed and made more accurate on the basis of the actual short term weather forecasts, which is used for the operational daily decisions.

- Experiments have shown that the Nitrogen additional fertilization is considerably affected by rainfall in May and June. The higher the monthly rainfall totals the higher the amounts of N needed.

- Irrigation advisory service has been developed jointly by the Meteorological Service and by the agricultural research institutions. A routine advice is issued by the Meteorological Service and is disseminated mainly by telex to the users in the irrigated areas. The method balances at weekly intervals the measured rainfall and the potential evapotranspiration calculated by the Penman equation. The results of this calculation, together with the crop weather consumption data (depending on the crop species and on the stage of crop development), together with the amounts of water applied for the last irrigation and the information on the soil type are used to compute the amount of supplementary irrigation needed.

As far as the potato crop is concerned, this irrigation advice is aimed mainly at the early potato growing regions, which are on one hand relatively warm, but on the other hand tend to be dry and need the supplementary irrigation.

- For frost protection the routine short term weather forecasts for 1-2 days and weather forecasts for agriculture for 5 days are used in all potato growing areas, but mainly in the early potato growing zone where the crop is grown at a higher risk in spring. The protective measures used are the spraying by water or covering of young plants by a thin layer of soil.

- The potato blight forecasts are issued by the Plant Protection Service. The forecast works on the basis of an empirical rule. The activity of the Meteorological Service is limited to the provision of rainfall data from selected stations. Actually a new method of potato blight forecasts is being developed and tested by agriculturalists. This method should replace the old one, which has been in use until now.
- For spraying against pests and diseases the routine short term weather forecast for 1-2 days is used (mainly rainfall and wind speed). Besides that the Meteorological Service is responsible for the flight forecasts for agricultural aircraft used.

- Modeling of the growth, development and yield of potato crop: Selected models used abroad are being tested in the agricultural research (the meteorological input data are: mean daily air temperature and amplitude, mean daily dew point, wind velocity and daily total of incoming short wave radiation).

- Weekly agrometeorological analysis of weather and of it's effect on the crop is carried out and published. Besides that there are regular weather bulletins and advisories to the farmers twice per week in TV. Weather information, mainly weather forecasts supplied by the meteorological Service is accompanied by the agricultural interpretation and advice given by agricultural specialists.

Switzerland

- Disease indices: The German model developed by Ullrich and Schröder on negative-prediction of potato blight epidemics has been adapted to the Swiss conditions. During the critical period the meteorological data are evaluated for the last 7 days for 18 stations and the results are disseminated by telex. The method is only successful if the field observations are made regularly and conscientiously.

Federal Republic of Germany

- Disease indices: A negative forecasting system is used to predict the earliest possible date when Phytophthora infestants may occur. For this purpose weekly and total Phytophthora indices are calculated based on hourly observations of air temperature, relative humidity and precipitation from the time of crop emergence. The results of the PHYTPROG service are made available to the plant protection offices in the weekly publication "Agrarmeteorologischer Wochenhinweis" as well as via view data. Then the plant protection offices prepare for the farmers recommendations, which are publicized via view data or made available by post and phone. Spraying forecasts are provided to the users by telephone, report or videotext.

- Weather Summaries: A weekly Agrometeorological Bulletin is issued by the Meteorological Office which includes weather statistics, phenological data, effects of weather on crops, soil moisture data and disease indices. The collected developmental stages are: seeding, emergence, covering the ground, surface, flowering, beginning of harvest.

- Frost warnings are also issued by the Meteorological Service.
German Democratic Republic

- **Disease indices:** A model called SIMPHYT I is used to calculate the first occurrence of potato late blight, while SIMPHYT II is used for optimization of the timing of the spray applications.

- **Modelling of growth and development:** Statistical models are developed to estimate crop yields.

The Netherlands

- **Modelling of growth and development:** Several simple static or dynamic simulation models are being developed by various National Research Institutes. Examples of such models are the Agro-ecological method (FAO method), the linear growth method and the simulation models SUCROS, CROP PRODUCTION, BACROS, POTATO and SWACRO.

- **Disease indices:**

  (i) Warning system on potato blight.

    (a) A meteorologist of the Met. Service and a plant pathologist of the Crop Protection Service are operating as a team so that, on the basis of the available meteorological and epidemiological information (including forecasted weather) decides on the broadcasting by radio of advice to farmers on the control of potato blight.

    (b) A simulation model on the development cycle of the fungus was developed by the Agricultural University of Wageningen. The objective of the model is to provide knowledge and understanding of the fungus-crop fungicide system.

  (ii) **Potato cyst nematodes:** A dynamic simulation model on the interactions between potato crop growth and potato cyst nematodes was developed by the Agricultural University of Wageningen.

Cyprus

- **Irrigation planning:** The water requirements of the crop are estimated on the basis of pan A evaporation measurements. The amount of water required for sprinkler irrigation is estimated to be 0.7 to 0.8 of pan A evaporation. Regarding the frequency of irrigation the method suggests that irrigation should be applied whenever 25 mm of pan A evaporation have been accumulated.

- **Disease indices:** The farmers are advised to continue control of Phytophthora Infestants when the meteorological conditions are favourable for disease development and spreading.

- **Weather Summaries:** A monthly Agrometeorological Report is issued during the growing season giving information of the past month weather conditions and their effect on crop growth and development.

- **Frost warnings:** Frost warnings are issued by the Forecasting Unit of the Meteorological Service.
U.S.S.R.

- **Irrigation planning**: To keep the tubers growing well and continuously, there must be no less than 20 mm and no more than 50 mm of available soil moisture in the arable layer at all times, and soil temperature at 10 cm must not go above 20-22°C.

- **Disease indices**: On the basis of the weather conditions and the development of the disease, the farmers are advised for spraying operations.

- **Modelling of growth and development**: Statistical and dynamic simulation models were developed to estimate the crop yield.
2.4 Harvest

Generally, weather forecasts are essential during the process of harvesting. Additionally in England, soil temperatures at 30 cm depth at 0900 GMT are available from synoptic stations. Soil temperatures below 8°C at harvest should be avoided in order to minimize bruising to the tubers. Furthermore, in Czechoslovakia to decide on the numbers of machinery which are needed by a farm for the harvest, a study of the climatologically conditioned workability throughout the harvesting season in different potato growing zones was carried out by the Meteorological Service. The relationship between the daily number of hours available for the work of the harvesting machines and the daily rainfall totals was expressed by the regression equations.

2.5 Storage and Transport

Monitoring of the storage environment and weather forecasts are used by many countries, in order to determine the optimum conditions for tubers. In Czechoslovakia, for the design and construction of large potato storages the temperature data (mean number of hours exceeding the limits of +3°C, +7°C and 10°C during the winter months) and the air humidity data are used.
Table 1. List of National Research Institutes engaged in potato production

<table>
<thead>
<tr>
<th>Country</th>
<th>National Research Institute</th>
<th>Address</th>
<th>Main Research Activities</th>
<th>Persons who could be conducted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cyprus</td>
<td>Agricultural Research Institute</td>
<td>Athalassa</td>
<td>Research and Breeding of Potato</td>
<td>Dr. N. Vakis</td>
</tr>
<tr>
<td>Czechoslovakia</td>
<td>Oseva KVSUB</td>
<td>Dobrovskeho 2366 580 03 R. Brod</td>
<td>Research and Breeding of Potato</td>
<td>Ing. B. Vokal, CSc.</td>
</tr>
<tr>
<td>&quot;</td>
<td>VCPU Hevlin</td>
<td>Hevlin 671 69 Hevlin</td>
<td>Irrigation of Crops</td>
<td>Ing. G. Hernetka, CSc.</td>
</tr>
<tr>
<td>&quot;</td>
<td>UKZUS-SOR</td>
<td>Zemedelska 1 a 662 65 Brno</td>
<td>Testing of Fungicides and Forecasts</td>
<td>Ing. R. Hruby, CSc.</td>
</tr>
<tr>
<td>Federal Republic of Germany</td>
<td>Biologische Bundesanstalt</td>
<td>D-8059 Grumbach</td>
<td>Potato breeding</td>
<td>Prof. Wenzel Batz</td>
</tr>
<tr>
<td>&quot;</td>
<td>Bundessortenamt</td>
<td>D-3163 Sehnde</td>
<td>Variety Testing</td>
<td></td>
</tr>
<tr>
<td>&quot;</td>
<td>Biologische Bundesanstalt fur Land-und Forstwirtschaft</td>
<td>D-3300 Braunschweig Messeweg</td>
<td>Variety Testing</td>
<td>Dr. Schober</td>
</tr>
<tr>
<td>&quot;</td>
<td>Bundesforschungsanstalt fur Land-wirtschaft</td>
<td>FAL 3300 Braunschweig Bundesallee 50</td>
<td>Potato breeding</td>
<td>Prof. Dr. Dambroth</td>
</tr>
<tr>
<td>&quot;</td>
<td>Max-Planck-Inst.</td>
<td>D-3057 Scharnhorst</td>
<td>Potato breeding</td>
<td></td>
</tr>
<tr>
<td>GREECE</td>
<td>Agricultural Research Center of Northern GREECE</td>
<td>Thessaloniki GR 54110</td>
<td>Physiology plant breeding, Seed production of horticultural plants, Renewable sources of energy</td>
<td>Dr. M. Grafiadellis</td>
</tr>
</tbody>
</table>
Table 1 (contd.). List of National Research Institutes engaged in potato production

<table>
<thead>
<tr>
<th>Country</th>
<th>National Research Institute</th>
<th>Address</th>
<th>Main Research Activities</th>
<th>Persons who could be conducted</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISRAEL</td>
<td>Israeli Extension Service</td>
<td>Arania St. Tel. Aviv.</td>
<td>Applied</td>
<td>Mr. Benjamin Gamliel</td>
</tr>
<tr>
<td></td>
<td>Volcanic Centre</td>
<td>Bet. Dagan</td>
<td>General, Modelling</td>
<td>Dr. David Levi</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Dr. Hovev Talpaz</td>
</tr>
<tr>
<td></td>
<td>Shaar Hanegev Enterprises</td>
<td>Shderot</td>
<td>Growth-Model</td>
<td>Mr. J. Roshan</td>
</tr>
<tr>
<td>NORWAY</td>
<td>Dept. Crop Science Agric. Univ. of Norway</td>
<td>P.O. B 41  N-1432 As NLH</td>
<td>Breeding</td>
<td>Prof. L. Roer</td>
</tr>
<tr>
<td></td>
<td>Agric. Res. Stn.</td>
<td>P.O.B.100, N-1432 As-NLH</td>
<td>Crop husbandry</td>
<td>Mr. J. Furunes</td>
</tr>
<tr>
<td></td>
<td>Norw. Pl. Prot. Inst.</td>
<td>P.O.B. 70, N-1432 As-NLH</td>
<td>Pest diseases</td>
<td>Mr. E. Forsund</td>
</tr>
<tr>
<td></td>
<td>Hveem Res. Farm</td>
<td>N-2856 Biltr</td>
<td>Crop husbandry storage</td>
<td>Dr. T. Kirkerod</td>
</tr>
<tr>
<td>POLAND</td>
<td>Institute of Potato</td>
<td>76-009 Bonin near Koszalin</td>
<td>Comprehensive studies, Genetics, cultivation, seed production, storage production, economics</td>
<td>Director: Prof. dr Edward Kapsa Assoc. Prof. Stanisikawa Roztopowicz</td>
</tr>
<tr>
<td></td>
<td>Inst. of Cultivation, Fertilizing and Pedology</td>
<td>24-100 Pulawy Osada Pakacowa</td>
<td>Agrotechnics</td>
<td>Director Prof. dr Stanisikaw Nawrocki Prof. dr Tadeusz Gorski</td>
</tr>
<tr>
<td></td>
<td>Institute of Plant Production</td>
<td>60-318 Poznan ul. Miczurina 20</td>
<td>Plant protection</td>
<td>Director Prof. Wkadyskaw Wegorek</td>
</tr>
<tr>
<td>Country</td>
<td>National Research Institute</td>
<td>Address</td>
<td>Main Research Activities</td>
<td>Persons who could be conducted</td>
</tr>
<tr>
<td>--------------</td>
<td>----------------------------</td>
<td>-----------------------------------------------------</td>
<td>--------------------------------------------</td>
<td>--------------------------------</td>
</tr>
<tr>
<td>PORTUGAL</td>
<td>UIAD</td>
<td>Universidade de Tras-os-Montes 5000 Vila Real-Portugal</td>
<td>Growing analysis</td>
<td>Mr. Fernando Martins</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tapada de Ajuda 1399 Lisboa Codex</td>
<td></td>
<td>Mr. Timotio Ferreira</td>
</tr>
<tr>
<td></td>
<td>ISA</td>
<td>Quindia do Marquess 2750 Oeiras - Portugal</td>
<td>Growth modeling</td>
<td>Dr. P. Aquiar Pinto</td>
</tr>
<tr>
<td></td>
<td>INIA</td>
<td>Tapada de Ajuda 1300 Lisboa - Portugal</td>
<td>Tests of new varieties</td>
<td>Mr. Lurdes Taborda</td>
</tr>
<tr>
<td></td>
<td>CNPPA</td>
<td>Tapada da Ajuda 1300 Lisboa - Portugal</td>
<td>Tests of new varieties</td>
<td>Mr. Joao Rego</td>
</tr>
<tr>
<td>SWITZERLAND</td>
<td>SWISS FEDERAL RESEARCH</td>
<td>Reckenhofstr. 191 CH-8046</td>
<td>Variety Tests Seed control Quality Research</td>
<td>W. Maag</td>
</tr>
<tr>
<td></td>
<td>STATION FOR AGRONOMY</td>
<td></td>
<td>Agronomy Research Virology Pathology</td>
<td>Dr. J. Rek</td>
</tr>
<tr>
<td></td>
<td>ZUERICH-RECKENHOLZ</td>
<td></td>
<td></td>
<td>Dr. F.A. Winiger</td>
</tr>
<tr>
<td>TURKEY</td>
<td>Field Crops Central Inst.</td>
<td>Lodumlu-ANK.</td>
<td>Field Crops</td>
<td>Mr. Baydur Valmac</td>
</tr>
<tr>
<td></td>
<td>Aegean Agricultural</td>
<td>Menemen-IZMIR</td>
<td></td>
<td>Mr. Ertug Fiyat</td>
</tr>
<tr>
<td></td>
<td>Research Institute</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>East Anatolian Agricult.</td>
<td>Erzurum</td>
<td>Field Crops</td>
<td>Mr. Muammen Saung</td>
</tr>
<tr>
<td></td>
<td>Research Inst.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UNITED KINGDOM</td>
<td>Institute of Arable Crops</td>
<td>Harpenden, Herts ALS 23JQ</td>
<td>Nematodes</td>
<td>Whitehead A.G.</td>
</tr>
<tr>
<td></td>
<td>Research Rothamsted</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Experimental Station</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Scottish Crop Research</td>
<td>Invergowrie, Dundee DDZ 5DA</td>
<td>Modelling Nematodes</td>
<td>McKerron, D.K.L.</td>
</tr>
<tr>
<td></td>
<td>Institute</td>
<td></td>
<td></td>
<td>Phillips, M.</td>
</tr>
<tr>
<td>Country</td>
<td>Potato varieties</td>
<td>Time of cultivation</td>
<td>Total growing period (days)</td>
<td>Specific Climatic constraints</td>
</tr>
<tr>
<td>--------------------------</td>
<td>------------------</td>
<td>---------------------</td>
<td>-----------------------------</td>
<td>-----------------------------</td>
</tr>
<tr>
<td>CZECHOSLOVAKIA</td>
<td>Rosy</td>
<td>Very early</td>
<td>120</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Ostara</td>
<td>Very early</td>
<td>122</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Radka</td>
<td>Half early</td>
<td>139</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Eba</td>
<td>Half late</td>
<td>147</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Svatava</td>
<td>Half early</td>
<td>134</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Kamyk</td>
<td>Late</td>
<td>154</td>
<td>-</td>
</tr>
<tr>
<td>FEDERAL REPUBLIC OF GERMANY</td>
<td>Granola</td>
<td>March to October</td>
<td>145</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Nicola</td>
<td>March to October</td>
<td>142</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Christa</td>
<td>March to July</td>
<td>123</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Hansa</td>
<td>March to October</td>
<td>145</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Aula</td>
<td>March to October</td>
<td>154</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Quarta</td>
<td>March to October</td>
<td>144</td>
<td>-</td>
</tr>
<tr>
<td>GREECE</td>
<td>Spunta</td>
<td>February-April</td>
<td>120</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Jaerla</td>
<td></td>
<td>90</td>
<td>Sensitive to low soil temperature and high soil moisture during seed tuber sprouting</td>
</tr>
<tr>
<td></td>
<td>Marfona</td>
<td></td>
<td>110</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Clauster</td>
<td></td>
<td>110</td>
<td>-</td>
</tr>
<tr>
<td>Country</td>
<td>Potato varieties</td>
<td>Time of cultivation</td>
<td>Total growing period (days)</td>
<td>Specific Climatic constraints</td>
</tr>
<tr>
<td>---------</td>
<td>------------------</td>
<td>---------------------</td>
<td>----------------------------</td>
<td>-----------------------------</td>
</tr>
<tr>
<td>ISRAEL</td>
<td>Desire</td>
<td>January-July</td>
<td>120-150</td>
<td>Hot spells</td>
</tr>
<tr>
<td></td>
<td>Alfa</td>
<td>January-September</td>
<td>130</td>
<td>Hail, sand storm</td>
</tr>
<tr>
<td></td>
<td>Cara</td>
<td>January-September</td>
<td>120-150</td>
<td>Drought</td>
</tr>
<tr>
<td></td>
<td>Atica</td>
<td>January-September</td>
<td>120</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Nicola</td>
<td>January-September</td>
<td>120</td>
<td>-</td>
</tr>
<tr>
<td>NORWAY</td>
<td>Beate</td>
<td>April-September</td>
<td>Early mainc.</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Saturna</td>
<td>&quot;</td>
<td>Early mainc.</td>
<td>Drought sensitive</td>
</tr>
<tr>
<td></td>
<td>Pimpernel</td>
<td>&quot;</td>
<td>Late mainc.</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Kerrs Pink</td>
<td>&quot;</td>
<td>Late</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Laila</td>
<td>&quot;</td>
<td>Early</td>
<td>-</td>
</tr>
<tr>
<td>POLAND</td>
<td>Irys</td>
<td>Very Early</td>
<td>130</td>
<td>Hoar frost -2°C and lower,</td>
</tr>
<tr>
<td></td>
<td>Frezja</td>
<td></td>
<td></td>
<td>Drought in the period of blossoming-ripening</td>
</tr>
<tr>
<td></td>
<td>Cynia</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ruts</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Koral</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sieglinde</td>
<td>Early</td>
<td>140</td>
<td>&quot;</td>
</tr>
<tr>
<td></td>
<td>Dalis</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sasanka</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Kalina</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Duet</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Country</td>
<td>Potato varieties grown in each country</td>
<td>Time of cultivation</td>
<td>Total growing period (days)</td>
<td>Specific Climatic constraints</td>
</tr>
<tr>
<td>---------</td>
<td>---------------------------------------</td>
<td>--------------------</td>
<td>-----------------------------</td>
<td>-------------------------------</td>
</tr>
<tr>
<td>POLAND</td>
<td>Bintje, Ronda, Abra, Elda</td>
<td>Fairly early</td>
<td>150</td>
<td>Hoar frost -2°C and lower.</td>
</tr>
<tr>
<td></td>
<td>Sokol, Sowa, Bryza, Certa, Atol</td>
<td>Fairly late</td>
<td>200</td>
<td>Drought in the period of blossoming-ripening</td>
</tr>
<tr>
<td></td>
<td>Flisák, Lenino, Uran, Tarpan, Narawa</td>
<td>Continued late</td>
<td>105-115</td>
<td>Frost occurrence and rain distribution</td>
</tr>
<tr>
<td></td>
<td>DESIREE, KENNEBEC</td>
<td>Mar/Apr-Jul/Aug</td>
<td>105-115</td>
<td>20-35</td>
</tr>
<tr>
<td></td>
<td>JERLA, SPURTA</td>
<td>Jan/Feb-Apr/May</td>
<td>90-100</td>
<td>16-30</td>
</tr>
<tr>
<td></td>
<td>ARRAN BANNER, ARRAN CONSUL</td>
<td>Mar/Apr-Jul/Aug</td>
<td>115-125</td>
<td>20-35</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>120-130</td>
<td></td>
</tr>
<tr>
<td>Country</td>
<td>Potato varieties</td>
<td>Time of cultivation</td>
<td>Total growing period (days)</td>
<td>Specific Climatic constraints</td>
</tr>
<tr>
<td>-------------</td>
<td>------------------</td>
<td>---------------------</td>
<td>-----------------------------</td>
<td>-------------------------------</td>
</tr>
<tr>
<td>SWITZERLAND</td>
<td>Bintje</td>
<td>April-September</td>
<td>About 150</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Eba</td>
<td>April-September</td>
<td>165</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Desiree</td>
<td>April-September</td>
<td>150</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Ostara</td>
<td>March-June</td>
<td>95</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Urgenta</td>
<td>April-September</td>
<td>150</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Nicola</td>
<td>April-September</td>
<td>155</td>
<td>-</td>
</tr>
<tr>
<td>TURKEY</td>
<td>Resy</td>
<td>October-February,</td>
<td>60</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Marfona</td>
<td>May-June</td>
<td>60</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Scala</td>
<td>&quot;</td>
<td>60</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Semena</td>
<td>&quot;</td>
<td>60</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Planta</td>
<td>&quot;</td>
<td>75</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Aula</td>
<td>&quot;</td>
<td>80-90</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Agria</td>
<td>&quot;</td>
<td>&quot;</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Ausonia</td>
<td>&quot;</td>
<td>&quot;</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Diamant</td>
<td>&quot;</td>
<td>75</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Premiere</td>
<td>&quot;</td>
<td>50</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Granola</td>
<td>&quot;</td>
<td>80-90</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Ilona</td>
<td>&quot;</td>
<td>&quot;</td>
<td>-</td>
</tr>
<tr>
<td>UNITED KINGDOM</td>
<td>Arran Comet</td>
<td>March-July</td>
<td>120</td>
<td>Frost</td>
</tr>
<tr>
<td></td>
<td>Maris Bard</td>
<td>&quot;</td>
<td>120</td>
<td>&quot;</td>
</tr>
<tr>
<td></td>
<td>Wilja</td>
<td>March-August</td>
<td>140</td>
<td>Drought</td>
</tr>
<tr>
<td></td>
<td>Maris Piper</td>
<td>April-September</td>
<td>150</td>
<td>&quot;</td>
</tr>
<tr>
<td></td>
<td>Cara</td>
<td>&quot;</td>
<td>150</td>
<td>&quot;</td>
</tr>
<tr>
<td></td>
<td>Romano</td>
<td>&quot;</td>
<td>150</td>
<td>&quot;</td>
</tr>
<tr>
<td>Phase</td>
<td>Agrometeorological information required</td>
<td>Contribution of Meteorology and operational data required</td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------------</td>
<td>----------------------------------------</td>
<td>--------------------------------------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preplanting</td>
<td>1. Assessment of the potential productivity of a given area.</td>
<td>Application of any growth and development models using average climatic records of solar radiation and temperature.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2. Physiological age of the seed tuber.</td>
<td>a) Reports of the prevailing weather conditions during the seed year. Temperatures are essential;</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>b) Calculation of degree-days above 4 °C from the date of breaking dormancy to planting date;</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>c) Estimation of chilling or heating requirements of a particular potato cultivar in order to obtain the optimum physiological age at planting date for selected dates of dormancy;</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>d) Weather forecasts.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3. Chilling in transport of seed tubers</td>
<td>Weather forecasts.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Planting</td>
<td>1. State of Soil</td>
<td>a) Soil moisture data (measured or estimated);</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>b) Weather forecasts.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2. Growing conditions</td>
<td>a) Soil temperatures at 10, 20 and 30 cm depths;</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>b) Forecasts of soil temperatures;</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>c) Establishment of relationships between soil and air temperatures.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phase</td>
<td>Agrometeorological information required</td>
<td>Contribution of Meteorology and operational data required</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-------------</td>
<td>----------------------------------------</td>
<td>--------------------------------------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Growing</td>
<td>1. Modelling of growth and development</td>
<td>Application of a simulation model using current meteorological data to estimate growth and development of the crop, to assess the effect of weather in the year to year variations in yield at a particular place, and to assist plant breeders to evaluate potentially useful plant traits.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>a) <strong>Strategic</strong> (long term) irrigation planning to assess crop water requirements during the growing season;</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>b) <strong>Tactical</strong> (daily) irrigation planning to estimate the current needs of the water requirements of the crop;</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>c) Weather forecasts;</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>d) Establishment of cost/benefit ratios.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2. Irrigation need</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3. Frost protection</td>
<td>a) Experiments to evaluate the effectiveness of each frost protection method;</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>b) Topoclimatological studies with respect to frost sensitivity of each area;</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>c) Statistical analysis of the occurrence of frosts (classification of frosts according to their types, probability distribution of frost free period, frost severity, etc).</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>d) Frost warnings;</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>e) Cost/benefit ratios.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phase</td>
<td>Agrometeorological information required</td>
<td>Contribution of Meteorology and operational data required</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-------</td>
<td>----------------------------------------</td>
<td>--------------------------------------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Disease indices and warning systems</td>
<td>a) Establishment of relationships between meteorological variables in the screen and the canopy during the day and night;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>b) Establishment of relationships between leaf wetness recorders and relative humidity in the screen;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>c) Collection of plant pathological data and relate them to various meteorological elements;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>d) Statistical analysis of the basic meteorological parameters which have an effect on the incidence and development of the disease;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>e) Establishment of warning systems or application of the existing ones;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>f) Determination of high risk areas using the established warning system;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>g) Spraying forecast;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>h) Estimation of soil pesticides residues based on soil moisture data;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>i) Establishment of cost/benefit ratios.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phase</td>
<td>Agrometeorological information required</td>
<td>Contribution of Meteorology and operational data required</td>
<td></td>
<td></td>
</tr>
<tr>
<td>------------------------</td>
<td>--------------------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Haulm destruction</td>
<td>a) Soil moisture data (state of the soil);</td>
<td>a) Soil moisture data (state of the soil);</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>b) Spraying conditions and weather forecasts.</td>
<td>b) Spraying conditions and weather forecasts.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Microclimate manipulation</td>
<td>Studies on the effects of shading, mulching and surface modifications on temperature, evapotranspiration and relative humidity and their effect on crop growth and development.</td>
<td>Studies on the effects of shading, mulching and surface modifications on temperature, evapotranspiration and relative humidity and their effect on crop growth and development.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Harvest</td>
<td>Time of harvest</td>
<td>a) Soil temperatures;</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>b) Soil moisture (state of soil);</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>c) Weather forecasts.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Storage</td>
<td>Store management</td>
<td>a) Store temperatures (measured or estimated) and relative humidity;</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>b) Probability of frost damage in stores;</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>c) Weather forecasts.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transport</td>
<td>1. Chilling of seed in transport</td>
<td>Weather forecasts</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2. Covering seed in transport</td>
<td>a) Effect of covering material on tuber temperature;</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>b) Weather forecasts.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
PART B: AGROMETEOROLOGICAL METHODS FOR
POTATO CROP PRODUCTION

The second part describes the various methods which are in operational use by various Meteorological Services and other National Research Institutes. For each method the following information is given:

1. OBJECT OF METHOD
   1.1 Objective
   1.2 Title

2. DESCRIPTION OF METHOD
   2.1 Output
   2.2 Description
   2.3 Input data (meteorological, crop, soil, management)
   2.4 Operational requirements
   2.5 Validity and constraints in application

3. VALIDATION/PROVEN USES

4. REFERENCES

   The required information which was extracted either from the literature or from the answers of the respondents.
1. **PREPLANTING**

1.1 **Physiological age**

1. **OBJECT OF METHOD**

1.1 Objective: To monitor and control potato-store temperatures in order to achieve optimum physiological age at the right time.

1.2 Title: Controlling physiological age for maximum early potato production by the use of degree-day readings.

2. **DESCRIPTION OF METHOD**

2.1 Output (expected results and accuracy): Accumulated degree-days above 4°C which can be used to estimate the amount of heating or cooling needed to reach the optimum physiological age by a given date for selected dates of dormancy break.

2.2 Description: The method is based on records taken in the farmer's store and compared with long-term records of degree-days from a suitable meteorological station. The mean temperature in the store is assumed to be 2°C above that in the screen. The method is graphical and enables the farmer to monitor and control his potato-store temperatures in order to achieve optimum physiological age (400-700 Cd) at the right time.

2.3 Input data. Meteorological data: Long term records of maximum and minimum temperatures, as well as current daily records.

Crop data: Date of breaking the dormancy.

2.4 Operational requirements (including computer requirements): Programmable calculator or a simple form for recording daily maximum and minimum temperatures and the accumulated degree-days.

2.5 Validity, limits imposed by basic concept, constraints in application: The assumption of the relationship between internal and screen temperatures is an over-simplification.
3. VALIDATION/PROVEN USES

The method can be used for each individual farm.

4. REFERENCES


Additional References


2. **PLANTING**

Soil temperatures and soil moisture measurements are required in order to determine the optimum planting date. Methods of estimating soil moisture are given in the next section under the heading of irrigation. Growth and developmental models can be also used to determine the optimum planting date (see for example SWARCO model, section 3.1). The following paragraphs are referred to the methods of estimating soil temperatures.

2.1 **Soil temperature**

2.1.1 Estimating daily maximum and minimum temperatures at 10 and 30 cm depths (United Kingdom).

1. **OBJECT OF METHOD**

1.1 Objective: To estimate average daily maximum and minimum temperatures at 10 and 30 cm depths under bare soil by fitting fourth order polynomials of day number to monthly averages.

2. **DESCRIPTION OF METHOD**

2.1 Output (expected results and accuracy)
Daily maximum and minimum temperatures at 10 and 30 cm depths.

2.2 Description: A least-squares regression analysis was performed to give an equation of the form:

\[ T = b_0 + b_1 SD + b_2 CD \]

where \( T \) = average (maximum or minimum) temperature on day \( D \), \( SD = \sin(2\pi D/365) \), \( CD = \cos(2\pi D/365) \), \( D \) = day number (1 Jan. = 1, etc.).

Least-squares regression analysis of the 10 and 30 cm maximum and minimum against 09 GMT readings at these levels was also performed, i.e.

\[ T = b_0 + b_1 X_1 + b_2 X_2 \]

where \( X_1 = 09 \) GMT 10 cm temperature under bare soil and \( X_2 = 09 \) GMT 30 cm temperature under grass.
2.3 Input data

Meteorological data: Average values of soil temperatures at 10-day intervals for daily maximum and minimum and 09GMT temperatures at 10 and 30 cm depths.

2.4 Operational requirements (including computer requirements): Micro-computer.

2.5 Validity, limits imposed by basic concept, constraints in application: The method is applicable only at the location where it was developed.

3. VALIDITY/PROVEN USES

The method was applied successfully in a number of climatological stations in England.

4. REFERENCES


2.1.2 Estimating daily maximum and minimum 10 cm soil temperatures from standard meteorological data (United Kingdom).

1. OBJECT OF METHOD

1.1 Objective: To estimate daily maximum and minimum soil temperatures at 10 cm depth from commonly available daily recordings of the 0900 GMT 10 cm soil temperature, daily sunshine hours (or solar radiation) and daily maximum and minimum air temperatures used separately or in combination.

2. DESCRIPTION OF METHOD

2.1 Output (expected results and accuracy)
The errors of calculating the daily mean soil temperature were normally less than 1.0 °C.

2.2 Description

(a) Estimating the daily minimum soil temperature at 10 cm depth
The minimum is estimated by deducting a constant from the 0900 GMT reading, since the minimum soil temperature normally occurs between sunrise and 0900 GMT. The constant is estimated to vary between 1.0 and 2.0 °C.

(b) Estimating the daily maximum soil temperature at 10 cm depth
Four empirical relationships were established using a combination of various parameters (0900 GMT 10 cm soil temperature, daily total solar radiation-measured or calculated and daily range of air temperatures).

2.3 Input data
Meteorological data: 0900 GMT 10 cm soil temperature, daily total solar radiation and daily range of air temperatures (maximum-minimum).

2.4 Operational requirements (including computer requirements)
Mini or micro-computer

2.5 Validity, limits imposed by basic concept, constraints in application. The effects of aspect, soil moisture, soil texture and crop cover are not included in the regression equation. The equations are site specific.
3. VALIDITY/PROVEN USES

These equations are well suited to the calculation of accumulated soil temperatures in entomological and crop emergence studies. Climatological statistics of 10 cm soil temperature can be also derived.

4. REFERENCES


2.1.3 Soil temperature and heat flow.

1. OBJECT OF METHOD

1.1 Objective: To describe the heat flow in the soil and determine the soil temperature at various depths.

2. DESCRIPTION OF METHOD

2.1 Output (expected results and accuracy)
Estimated soil heat fluxes and soil temperatures.

2.2 Description

Numerical methods are used to solve differential equations for heat transport. The soil is divided into a number of layers of specified depth with appropriate boundary conditions. The thermal properties of soil materials are specified from the literature.

2.3 Input data

Meteorological data: Maximum and minimum air temperature.

Soil data: Water content in the soil depth of the soil and thermal properties of the soil.

2.4 Operational requirements (including computer requirements)
Minicomputer. Programmes are written in BASIC.

2.5 Validity, limits imposed by basic concept, constraints in application: The boundary layer conductance is assumed to be known.

3. REFERENCES


Additional References


2.1.4 Prediction of soil temperature  
(Federal Republic of Germany)

1. OBJECT OF METHOD

1.1 Objective: To predict the average daily soil temperature and its amplitude at various depths of soil ranging from 5 to 50 cm, using air temperature and solar radiation data.

1.2 Title: Bodentemperaturvorhersagemodel

2. DESCRIPTION OF METHOD

2.1 Output (expected results and accuracy)  
Maximum and minimum soil temperatures at the depths of 5, 10, 15, 20, 30, 40 and 50 cm.

2.2 Description

The extreme soil temperatures at 5 cm depth are estimated from regression analysis using air temperature and sunshine duration data. From these estimations the soil heat fluxes can be calculated when the soil characteristics are known and assuming a sinusoidal diurnal curve of soil temperature (Fig. 1).

2.3 Input data

Meteorological data: Mean daily air temperature at the screen level, daily minimum temperature and sunshine duration or solar radiation data.

Soil data: Thermal characteristics of the soil.

2.4 Operational requirements: Microcomputer.

2.5 Validity, limits imposed by basic concept, constraints in application: Simple but mostly empirical.

3. REFERENCES

Langholz, H. Bodentemperaturvorhersagemodel.  
BODENTEMPERATURVORHERSAGEMODELL

LUFT 2 m \( T_L \)

SONNENSCHEIN DAUER

GLOBAL-STRAHLUNG

LUFT 2 m \( T_L \; \text{MIN} \)

BODEN \( T_B \)

2.5, 10, 20, 30 cm

TAGESAMPLITUDE BODEN 5 cm \( \Delta T_B \)

BODENFEUCHTE

BODEN \( T_B \; \text{MAX} \) 5 cm

- \( T + \Delta T_B / 2 \)

TAGESGANG BODEN 5 cm

TAGESTUNGEN:
\[ T_B = T_B \; \text{MIN} + (T_B \; \text{MAX} - T_B \; \text{MIN}) \times \sin \left( \frac{T_B \; \text{cm}}{11.2} \right) \]

NACHTSTUNGEN:
\[ T_B = T_B \; \text{MIN} \times (T_B \; \text{SU} - T_B \; \text{MIN}) \times \exp \left( \frac{-h}{11.2} \right) \]

WARMLEITGEICHUNG

\[ \frac{\partial T}{\partial t} = K \times \frac{\partial^2 T}{\partial x^2} \]

TAGESGANG BODEN

10, 15, 20, 30, 40, 50 cm

\[ T_B = T_B \; \text{MIN} + T_B \times e^{-F \pi x} \times \sin \left( w t + \phi \right) \]

Flussdiagram zur Erstellung der Bödentemperaturvorhersage
3. GROWING SEASON

This section is divided into four subsections, i.e.

(a) Modelling of growth and development of potato;
(b) Soil moisture and irrigation;
(c) Disease warning systems; and
(d) Spraying forecasts.

3.1 Modelling of growth and development of potato

Mathematical modelling provides the basis for an analytical framework to identify the effects of the environmental variables on crop growth and development. Crop growth and development models can be used for a number of purposes:

1. To study climate-crop interactions and evaluate the effects of climatic variability on risk of production;

2. To estimate the potential yield in a given area and develop yield forecasts.

3. To assist plant breeders in finding and evaluating potentially useful plant traits;

4. To identify research priorities; and

5. To assess several crop management strategies.

Generally, models can be classified into two main groups, i.e. (a) the static and (b) the dynamic simulation models (Table 4). The static models are essentially statistical in their mathematical context and use some sort of regression technique. The variables which are used in such models are usually integrated seasonal totals of yield, rainfall, temperature and radiation. It is important to select such weather variables which have more physical and physiological importance. The static models can be further subdivided into four types depending on the environmental variables used in the regression equations, i.e. (i) temperature-and water-yield relationships; (ii) radiation-interception models; (iii) crop growth rate and effective length of the growth period; and (iv) transpiration efficiency models. Most of these models are used for predictive purposes. Apart from the first method which is applicable in the climatic region where it was developed the rest methods have some degree of physiological meaning.

The second group, i.e. the dynamic simulation models can be further subdivided into two types depending on the complexity of the model and the amount of knowledge and data about the crop, soil and weather which are required, i.e. (i) simple dynamic or summary models and (ii) comprehensive dynamic simulation models (Table 4). These models are generally explanatory in nature and have a high degree of physiological and morphological detail.
A brief general description of the static models is given in the following sections. However, more detail information is given for the dynamic simulation models, in a form similar to CARS-FOOD referral system. Only, a limited number of these models are in operational use by various Meteorological Services. Most of them are used for research purposes.
3.1.1 Static models

(a) Temperature - and weather-yield relationships

Examples of such models are given in the technical Note No. 174 of WMO (1982) and in the Report prepared by the Working Group on Agricultural Meteorology of Regional Association VI of WMO (1986). Furthermore, it should be added that such models exist in Hungary and Poland as it is indicated in their answers of the supplied questionnaire prepared by the relevant Working Group of RA-VI. A multiple regression model for yield estimates obtained from CARS-FOOD Climate Applications Referral System (WMO, WCP-67, 1984), is presented in the following section. Furthermore, two multiple regression models, obtained from Poland are also presented.

1. OBJECT OF METHOD

1.1 Objective: Early information about the production situation of main crops in EC countries, to enable governments to react with imports or exports

1.2 Title: Multiple Regression Models for Yield Estimates

2. DESCRIPTION OF METHOD

2.1 Output (expected results and accuracy)

Predicted values of yield in t/ha averaged on a country basis

2.2 Description

The models are based on monthly weather data and trends. Multiple regression equations are set up for each month from January until harvest and for each weather station. Necessary number of weather stations depends on the geographical situation of the country and the planted area of the crop. Results of all stations are summarized to an average for each month and over the months to provide a final forecast. After each month a new forecast is possible which includes the results of the preceding months. Errors decrease with the advancing of season.

2.3 Input data

Meteorological data: Monthly averages or sums for: minimum and maximum temperature, sunshine, precipitation, wind speed, relative humidity, number of wet days (rain>1.0 mm).

Not all these weather data are used in all models
2.4 Operational requirements (including computer requirements)

Computer sufficiently large to accommodate multiple regression programmes needed for calculating equations required for predictions. Forecasts themselves can be made by hand or by using a small pocket computer.

2.5 Validity, limits imposed by basic concept, constraints in application

Application of regression type models limited by the existing historical data set for weather and yields. Selection or aggregation of weather data may reduce statistical problems with low numbers of remaining degrees of freedom. Necessary to produce prediction equation by multiple regression for each single case (crop, country).

3. VALIDATION/PROVEN USES

- Used since 1978 for official forecast for the whole of the European Community area (43 weather stations for all the EC)

- Used in Germany (F.R.) since 1973

- Relative errors of forecasts vary from country to country (3-8%), with crops (3-5%), and are on average 4% with a range from 1-10% for forecasts in a single country for a single crop. Models have been developed for winter wheat, winter rye, winter barley, spring barley, oats, total cereals, maize, rice, potatoes, sugar beets.

4. REFERENCES


1. OBJECT OF METHOD

1.1 Objective: Prediction of potato crop yield based on the effects of meteorological conditions.

1.2 Title: Potato crop forecasting

2. DESCRIPTION OF METHOD

2.1 Output yields of potato from various areas.

2.2 Description: Statistical and graphic method. Multiple regression Ezekiel-Fox method of successive approximations

2.3 Input data

Meteorological data: Total precipitation, humidity index (function of precipitation and mean air temperature), mean deficit of air humidity at 13 p.m., number of days with frost.

2.4 Operational requirements: Minicomputer

2.5 Validity, limits imposed by basic concept, constraints in application: Applicable only to climatic conditions of Poland.

3. VALIDITY/PROVEN USES

The method can be applied for the forecasting of yields in greater administrative areas.

4. REFERENCES

Demidowicz G. Gorski T. Bonitacja klimatu dla uprawy ziemniskow.

Gorski T. and others. Prognoza plonów ziemniaków (Forecast of potato crops - typed text).

5. Contact

Prof. dr Tadeusz Gorski
Instytut Uprawy, Nawozn尼斯 i Gleboznawstwa
(Institute of Cultivation, fertilization and Pedology)
24-100 PULAWY
Osada Palacowa
1. OBJECT OF METHOD

1.1 Objective: An attempt to evaluate the usefulness of the area for potato cultivation (late varieties), based on analysis of meteorological conditions.

1.2 Title: Effect of meteorological conditions on the crop and content of starch in potato

2. DESCRIPTION OF METHOD

2.1 Output: Yields estimates and content of starch in bulbs

2.2 Description: Statistical method - multiple regression considering meteorological elements in various periods of potato growth. Studies were carried out separately for 5 soil groups. They allow to find out the essential differences in the influence of meteorological conditions on the yield and the content of starch in potato cultivated in various soils.

2.3 Input Data

Meteorological data: Temperature, precipitation number of days with precipitation, number of fair days.

2.4 Operational requirements: Computer

2.5 Validity, limits imposed by basic concept, constraints in application: The method can be applied in similar soils and climatic conditions.

3. VALIDATION /PROVEN USES

Better exploitation of the environment.

4. REFERENCES


5. Contacts

Dr. eng. Teresa Tomaszewska, Institute of meteorology and Water Management 01-673 Warszawa, Podlesna 61 (Department of Agrometeorology).
(b) **Light interception models**

For potato crops growing free from water stress and disease, close linear relationships between crop growth rate, total and tuber dry weights and the amount of PAR intercepted by the crop have been demonstrated. Acceptance of this linear relationship, enables the potential yield of tubers to be calculated as a product of three factors: (a) the total amount of PAR intercepted radiation by the crop canopy, (b) the efficiency of its conversion to dry matter (E) which varies between 2.5 to 3.4 g DM MJ⁻¹ of PAR and (c) the harvest index (HI) which varies between 0.6 and 0.8.

However, the actual yield (Ya) of the crop can be reduced either by shortage of water and nutrients, high or low temperatures, soil structure and salinity and various agronomical practices. Additionally, diseases, pests and weeds can further reduce the yield. Therefore, the actual yield can be a product of a number of reduction factors which influence the growth and development of the crop and the potential yield (Ym) which depends on the climatic conditions and the genetic potential of the crop.

(c) **Crop growth rate and effective length of the growth period**

A simple quantitative approach to study the effects of the environment on crop yield has also been established recently by Monteith (1981) and Monteith and Scott (1982). The total dry weight of the crop at harvest (W) is related to the maximum crop growth rate (Cm) and the effective length of the growth period (tg-tl), where tl is the time lost as a consequence of incomplete light interception at the beginning of growth and the senescence in the period before harvest. Another component of tl is the time lost during drought when the maximum potential deficit of soil water exceeds the limiting deficit determined by the soil type and rooting depth of the crop. The maximum crop growth rate for C₃ plants, such as potato, in the temperate regions is estimated around 20 g DM m⁻²d⁻¹. Therefore, the effects of the environmental factors on dry matter production can be identified through the effects of temperature, radiation and water on the length of the effective period of growth (tg-tl) and on the maximum crop growth rate (Cm).

(d) **Transpiration efficiency**

An alternative approach to determine the effects of water on crop yield can be established through the concept of "transpiration efficiency" which is considered as the ratio of yield to transpiration. Tanner (1981) has established a linear relationship between tuber dry matter yield and the ratio of
transpiration to average daytime saturation vapour pressure deficit. The relationship is essentially derived by dividing the rate of leaf photosynthesis to transpiration rate expressing both variables in terms of drop of the concentrations of CO₂ and water vapour across a network of resistances (Fischer and Turner, 1978; Monteith, 1981; Tanner, 1981).

In order to quantify the effect of water stress on crop yield, Doorenbos and Kassam (1979) used the empirical relationship between relative yield decrease (1-Ya/Ym) and the relative evapotranspiration deficit (1-ETa/ETm). The yield response factor (Ky) is low during the early vegetative stage (0.45) and ripening period (0.2), while during tuber initiation and yield formation periods, it is about 0.8. This indicates that the decrease in yield due to water deficit is relatively small during the early vegetative stage and ripening period and relatively large during the yield formation period. Similar empirical relationships were established recently by several workers in semi-arid areas (Shalhevet et al., 1983).

REFERENCES


<table>
<thead>
<tr>
<th>Model</th>
<th>Equations and variables</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) Static models</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(i) Temperature and water yield relationships</td>
<td>Yield vs Temperature and rainfall</td>
<td>WMO, 1982</td>
</tr>
<tr>
<td></td>
<td>Yield vs Growing degree-days</td>
<td>Benoit and Grant, 1980</td>
</tr>
<tr>
<td></td>
<td>Yield vs Rainfall</td>
<td>Harris, 1978</td>
</tr>
<tr>
<td></td>
<td>Yield vs Evapotranspiration</td>
<td>Penman 1962; 1970; Peddes &amp;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>van Wijk, 1977</td>
</tr>
<tr>
<td></td>
<td>Yield vs Soil moisture deficit</td>
<td>Evans and Neild, 1981</td>
</tr>
<tr>
<td></td>
<td>Yield vs Plant water deficit</td>
<td>Benoit and Grant, 1980</td>
</tr>
<tr>
<td></td>
<td>Yield vs Rainfall and Temperature</td>
<td>Tomaszewska, 1972</td>
</tr>
<tr>
<td>(ii) Radiation interception</td>
<td>Maximum Yield ((Y_m)) = Intercepted \times Efficiency \times Harvest\</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(\quad \text{Radiation index}) (= \frac{\text{g m}^{-2}}{\text{MJ m}^{-2}}) (= \frac{\text{g DM MJ}^{-1}}{(\text{yr}^{-1})}) (= \frac{\text{Scott index}}{\text{yr}^{-1}})</td>
<td>Monteith, 1977; Sibma, 1977;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>van der Zaag and Burton, 1978;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>and Wilcockson, 1978;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Allen and Scott, 1980; Heath and</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Roberts, 1981; Khurana and</td>
</tr>
<tr>
<td></td>
<td></td>
<td>McLaren, 1982; Harris, 1983;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Versteeg, 1985; Burstall and</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Harris, 1986; Haverkort and</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Harris, 1986; Jefferies and</td>
</tr>
<tr>
<td></td>
<td></td>
<td>van der Zaag, 1984; Burton, 1981.</td>
</tr>
<tr>
<td>(iii) Crop growth rate and effective length of the growth period</td>
<td>Actual yield ((Y_a)) = (Y_m \times \text{Reduction coefficients})</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total crop dry weight at harvest ((W)) = crop growth \times length of growth period (= \frac{\text{g m}^{2}}{\text{yr}^{-1}}) (= \frac{\text{g yr}}{(\text{yr}^{-1})})</td>
<td>Monteith, 1981; Monteith, and</td>
</tr>
<tr>
<td></td>
<td>Maximum Effective weight of growth period (= \frac{\text{g m}^{2}}{\text{yr}^{-1}}) (= \frac{\text{g yr}}{(\text{yr}^{-1})})</td>
<td>Scott, 1982.</td>
</tr>
<tr>
<td>(iv) Transpiration efficiency</td>
<td>(a) Yield/Transpiration (= \frac{\text{constant(K)}}{\text{average daytime saturation vapour pressure deficit}})</td>
<td>Rijtema and Endrodi, 1970;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fischer &amp; Turner 1978;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Monteith, 1981; Tanner, 1981;</td>
</tr>
<tr>
<td></td>
<td>(b) Relative yield decrease (= \frac{\text{Response} \times \text{Relative evapo-factor(Ky) \times transpiration deficit}}{(1-Y_a/Y_m)})</td>
<td>Doorenbos and Kassam, 1979;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Shalhevet et al., 1983.</td>
</tr>
</tbody>
</table>
### Dynamic simulation models

#### (i) Simple dynamic models

<table>
<thead>
<tr>
<th>Name of the model</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Wageningen methods</strong></td>
<td></td>
</tr>
<tr>
<td>2. Linear growth method</td>
<td>Versteeg and van Keulen, 1986; Ridder de et al., 1982</td>
</tr>
<tr>
<td>3. SUCROS model modified for potatoes (a summary model)</td>
<td>Van Keulen et al., 1982; van Keulen and de Milliano, 1984; Spiertz et al., 1984; Versteeg and van Keulen, 1986; Marletto and van Keulen, 1984;</td>
</tr>
</tbody>
</table>

| (b) Potato growth and yield                 | Mackerron and Waister, 1985; Mackerron, 1985                              |
| (c) Potato growth on the plant at community level | Fishman et al., 1985a; Fishman et al., 1985b; Dumanski and Stewart, 1981; Stewart, 1981; Sands and Hackelt (1979) |
| (d) Crop production potentials             |                                                                           |
| (e) Pocket-calculator model                |                                                                           |

#### (ii) Comprehensive dynamic simulation models

| CROP PRODUCTION                            |                                                                           |
| BACROS                                      |                                                                           |
| POTATO                                      |                                                                           |
| SWACRO                                      |                                                                           |

Potato growth and development

Potato growth and development

<table>
<thead>
<tr>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Versteeg and van Keulen, 1986; Ridder de et al., 1982</td>
</tr>
<tr>
<td>Van Keulen et al., 1982; van Keulen and de Milliano, 1984; Spiertz et al., 1984; Versteeg and van Keulen, 1986; Marletto and van Keulen, 1984;</td>
</tr>
<tr>
<td>Mackerron and Waister, 1985; Mackerron, 1985</td>
</tr>
<tr>
<td>Fishman et al., 1985a; Fishman et al., 1985b; Dumanski and Stewart, 1981; Stewart, 1981; Sands and Hackelt (1979)</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>
3.1.2 Dynamic simulation models

3.1.2.1 Simple dynamic models

To improve accessibility to potential users who are interested in practical applications, some comprehensive models have been reformulated into less detailed summary models. Such models can be used mainly for predictive purposes and the amount of agrometeorological data which are required to run them are generally available from agrometeorological stations. The simple dynamic models can be subdivided into: (a) the Wageningen methods; (b) the simple growth model developed by Mackerron and Waister (1985) in England; (c) the growth model at plant community level developed by Fishman et al. (1985) in Israel; (d) the potential crop production model (Stewart, 1981; Dumanski and Stewart, 1981) developed in Canada and (e) the pocket-calculator model for predicting yield and development in potatoes with a number of empirical and statistical functions, developed in Australia (Sands and Hackett, 1979).

The Wageningen methods are then subdivided into three types differing in their complexity and sophistication used, i.e. (1) the Agro-ecological zone method (or FAO method); (2) the Linear growth model; and (3) the SUCROS model modified suitably for potatoes. All these models originate from the same source and start from the concept described by de Wit (1965) and amended by Goudriaan and van Laar (1978), and Goudriaan (1986), to calculate gross CO$_2$ assimilation for a standard crop from a given value of maximum assimilation rate at light saturation.
(a) Wageningen methods

(i) Agro-ecological zone method (or FAO method)

1. OBJECT OF METHOD

1.1 Objective: Assessment of potential food crop production based on a physical and biological approach and for rainfed agriculture

Title: FAO Agro-ecological zones model (AEZ)

2. DESCRIPTION OF METHOD

2.1 Output (expected results and accuracy)

A land suitability classification - extents of land variously suited to the production of crops at high and low-level inputs

2.2 Description

Dynamic model including a series of sub-models:

(1) Land utilization types
(2) Division of crop according to their photosynthetic responses
(3) Information on soil requirements of different crops
(4) Quantitative climatic inventory
(5) Soil inventory
(6) Definition of agro-ecological zones
(7) Matching climatic inventory with crop groups, calculation of biomass yields
(8) Soil requirements of crops matched with soil units
(9) Estimation of benefit/cost ratio of crop production
(10) Combination of sub-models into a land suitability classification

2.3 Input data

Meteorological data: Monthly averages of: rainfall, maximum-minimum-mean-day-night temperatures, vapour pressure, wind speed, duration of bright sunshine,

Crop data: - Ecological requirements and characteristics of crop species
- Crop calendars and length of their growing cycles

Soil data: - Soil physical and chemical characteristics

Management data: - Information on low and high level inputs
2.4 Operational requirements (including computer requirements)

Heavy - IBM 370 (Programmes written in Fortran)
Sub-programme on climatic inventory developed on desk-computer

2.5 Validity, limits imposed by basic concept, constraints in application

Validity tested on continental and national scales. If used on smaller scales the notion of the length of the growing season should be based on a probabilistic distribution derived from analysis of rainfall variability.

3. VALIDATION/PROVEN USES

Comparisons with assessments obtained from many FAO projects and reports show that the AEZ principle produces good results in several individual countries.

REFERENCES


(ii) **Linear growth model**

1. **OBJECT OF METHOD**

1.1 **Objective:** To predict the potential yield of various crops from simple calculations.

1.2 **Title:** Linear growth model

2. **DESCRIPTION OF METHOD**

2.1 **Output (expected results and accuracy)**

Total and harvested part of crop dry weight. The method produced predictions of production potentials of irrigated crops in different environments similar to those obtained from comprehensive simulation models.

2.2 **Description**

This method is based on the assumption that a typical growth curve is basically identical for any crop and can be characterized by (i) an exponential growth stage, (ii) a linear growth stage and (iii) a maturation stage. For potatoes, the total dry matter production (DM) in Kg/ha is given by the equation

\[ DM = 2800 + 0.42xLGR + 0.5x(0.25xLGR) \]

or

\[ DM = 2800 + 0.545xLGR \]

where LGR is the linear growth rate and is a function of the average daily potential gross assimilation for a closed crop canopy at the given site, the maintenance and growth respiration of the crop and the leaf area index of the crop, and \( p \) is the length of the growth period.

2.3 **Input data**

**Meteorological data:**
- Mean values of solar radiation and maximum and minimum temperatures during the growth period.

**Crop data:**
- Length of the growth period.
- Ecological requirements and characteristics of crop species.

2.4 **Operational requirements (including computer requirements)**

Micro-computer or pocket calculator.

2.5 **Validity, limits imposed by basic concept, constraints in application.**

Validity tested against 57 data sets for different environments for latitudes between 0 and 40°.
3. VALIDATION/PROVEN USES

Comparison of predictions with actual measurements showed good agreement. The model can be used for the establishment of an early warning system on basic food crop production at a national or regional level.

REFERENCES


(iii) **Summary model: SUCROS**

1. **OBJECT OF METHOD**

1.1 Objective: To simulate the growth and development of a potato crop at crop production levels 1 and 2 using a relative simple model (summary model)

1.2 Title: SUCROS model

2. **DESCRIPTION OF METHOD**

2.1 Output (expected results and accuracy)
Growth pattern of a potato crop.

2.2 Description

The model simulates the time course of dry matter production of a crop, in dependance of daily total irradiation, air temperature and soil moisture. The dry matter produced is divided into roots, leaves, stems and tubers. Partitioning factors are introduced as a function of the phenological state of the crop.

Simulation of soil water balance is required to account for temporary deficiencies in water supply. Sources of water are only rainfall and irrigation. Part of the rain is lost due to interception by the plant cover. The main process of depletion of soil water reserves are uptake by plants, evaporation of soil water to the atmosphere and drainage below the maximum rooting depth. The soil is divided into horizontal layers and water is redistributed by flow from one layer to another. The time step of the model is one day, but 10-day averages can be also used.

2.3 **Input data**

- Meteorological data:
  - Total daily radiation, maximum and minimum air temperatures, daily rainfall, mean daily relative humidity and daily run of wind

- Crop data:
  - Ecological requirements and characteristics of crop species
  - Crop calendars and length of their growth cycles.

- Soil data
  - Soil physical and chemical characteristics

2.4 **Operational requirements (including computer requirements)**

Microcomputer
2.5 Validity, limits imposed by basic concept, constraints in application.

There is a need for better understanding of factors governing crop development and the morphogenesis of leaves and tubers, the rooting pattern and the activity of the roots during the growth cycle and for crop adaptation to stress factors.

3. VALIDATION/PROVEN USES

Experimental data showed a good agreement with those obtained from the simulation. Predictions of the pattern of crop growth can be used by the extension service and farmers to improve farming practices.

REFERENCES


Marletto, V and van Keulen H., 1984. Winter wheat experiments in the Netherlands and Italy analyzed by the SUCROS model pp.61.


(b) A simple model of potato growth and yield (England)

1. OBJECT OF METHOD

1.1 Objective: To provide an estimate of the potential yield of a potato crop in a given environment with temperature and radiation as limiting factors.

1.2 Title: A simple model of potato growth and yield.

2. DESCRIPTION OF METHOD

2.1 Output (expected results and accuracy)

Potential production of a given area.

2.2 Description

The development of the crop is divided into phases which are easily recognisable and the rate at which the crop passes through these phases is calculated using experimentally derived relationships and simple meteorological variables. Production of total dry matter is calculated as a function of intercepted solar radiation and is partitioned empirically between tops and tuber. Table 5 shows the procedure of calculating the potential yield of potato from the model.

2.3 Input data

M{\textit{Meteorological data:}} - Daily Maximum and Minimum soil temperatures at 10 cm depth, Daily Maximum and minimum air temperatures, total solar radiation.

Crop data - Date of planting, emergence, canopy closure and haulm destruction

2.4 Operational requirements (including computer requirements Microcomputers

2.5 Validity, limits imposed by basic concept, constraints in application.

Where pre-sprouted seed tubers are used the estimates of date of 50% emergence are unsatisfactory. The model underestimates early growth in the period from emergence to canopy closure.
3. VALIDATION/PROVEN USES

The sensitivity analysis of the model can be used for the estimation of the possibilities for yield improvement by breeding or by cultural manipulation. The model has shown to be successful in its aims of providing an estimate of potential yield using only simple inputs.

REFERENCES


Table 5: THE CALCULATION OF POTENTIAL YIELD OF POTATO
The calculation is made in several steps, as described.

(1) The time from planting to sprouting.
( Unsprouted seed tubers): 125 degree-days above 5 C using soil
    temperature at 10 cm depth required for sprout development.
(2) Duration of extension of sprouts:
    1 mm per degree-day above 2 C using soil temperature at 10 cm
    depth.
(3) The time from emergence to canopy closure.
    Initial leaf area = 25 cm² per plant. Leaf relative growth rate
    (R) is a function of mean temperature (T<sub>o</sub>) above 2.4 C using the
    average of air maximum and minimum temperatures.
    \[ R = 0.01333 T_o \]
    Leaf area (A<sub>t</sub>) is calculated using daily (or weekly) mean air
    temperatures as:
    \[ A_t = A_{(a-t)} \exp(Rt) \] where t is the interval in days. Leaf area
    index, \( L = \rho A \) where \( \rho \) is the plant density (plant m⁻²)
    Canopy closure is recognized when \( L = 3 \)
(4) The solar radiation intercepted between emergence and canopy
    closure.
    \[ \sum_{t=e}^{c} I = \sum_{t=e}^{c} SL/3 \]
    where S is the incident radiation and I the radiation intercepted
    each day and e and c are limits representing dates of emergence
    and canopy closure.
(5) The solar radiation intercepted between canopy and haulm
    destruction.
    \[ \sum_{t=c}^{d} I = \sum_{t=c}^{d} S \]
    where d is the limit representing date of haulm destruction.
(6) Dry matter production, D (g m⁻²)
    \[ D = \left( \sum_{t=e}^{c} I + \sum_{t=c}^{d} I \right) 1.84 \]
    \( (\sum I \) is expressed in MJ m⁻²)
(7) Dry matter partitioning
    \[ T = 0.75 D \]
    where T is the dry matter in the tubers.
(8) Tuber yield, Y (g m⁻²)
    \[ Y = 5T \]
Simulation model of potato growth and development (Israel)

1. OBJECT OF METHOD

1.1 Objective:

1. To build a model describing fundamental physiological phenomena in potato development, taking into account environmental and managerial effects.

2. To be used as a research tool for understanding the main physiological processes.

1.2 Title: Simulation model of potato growth and development at plant community level.

2. DESCRIPTION OF METHOD

2.1 Output (expected results and accuracy)

Daily dry matter production, total and its distribution to four plant organs: leaves, stems, roots, tubers. Prediction of LAI and soil moisture.

2.2 Description

The model is constructed on the level of the plant community. The main control factors considered in the model are irrigation, fertilization and timing of harvest. The physiological processes which are simulated are the following: photosynthesis, respiration, partitioning of dry matter, leaf area and root growth, soil water distribution, uptake of water by roots and transpiration (Fig. 2). The time step for the simulation of general dynamic processes is one day. However, to describe some important physiological processes during a day, the simulation is performed by subroutines with hourly time steps.

2.3 Input data

Meteorological data:
- Hourly solar radiation values and daily maximum and minimum temperatures and pan A evaporation.

Crop data:
- Ecological requirements and characteristics of crop cultivars (seed size)
- Crop calendars and length of their growth cycle (planting date, emergence date)
- Age of seed tubers

Soil data:
- Soil moisture, soil depth
2.4 Operational requirements (including computer requirements)
Mini or microcomputers

2.5 Validity, limits imposed by basic concept, constraints in application.
Validity tested on national scale.

3. VALIDATION/PROVEN USES

The predictions of the model showed a good agreement with those obtained from field measurements. The model can be used as a decision-making tool for deciding on nitrogen fertilization and on timing of harvest.

REFERENCES


Fig. 2. Basic block diagram of the model
(d) **Crop production potentials**

1. **OBJECT OF METHOD**

1.1 **Objective:** To compute:

   a) growing season climatic conditions
   b) growing season water balance
   c) estimates of crop biomass, yield and production potential

   **Title:** Crop Production Potentials

2. **DESCRIPTION OF METHOD**

2.1 **Output (expected results and accuracy)**

Biomass produced during the growing season, yield estimates, and production potential mapped on a scale of 1/5000,000.

2.2 **Description**

The model has a physical basis and incorporates climatic data, crop phenological data and soil limitations.

2.3 **Input data**

- **Meteorological data:**
  - Climatological monthly normals: maximum- minimum temperatures, rainfall, snowfall, wind speed, vapour pressure, global radiation, duration of bright sunshine.

- **Crop data**
  - For calibration purposes: yield
    - For estimation purposes: crop type characteristics, maximum leaf area index, maximum growing season length, moisture use efficiency, harvest index

- **Soil data**
  - Soil moisture holding capacity.

- **Derived data**
  - 5 sub-models.

2.4 **Operational requirements (including computer requirements)**

Heavy: IBM 360/370 or similar (programme written in Fortran)
2.5 Validity, limits imposed by basic concept, constraints in application

The model:

a) uses long term climatic normals, not daily information
b) is based on growing season averages
c) does not consider various crop development stages
d) uses bulk crop phenological characteristics
e) is applicable to large areas on a long-term basis only
f) does not take into account management variations (i.e. fertilizers, pesticide use, etc.)

3. VALIDATION/PROVEN USES

Made on long-term yield estimate (Canada)

4. REFERENCES


5. AVAILABILITY/SOURCES OF ASSISTANCE FOR FUTURE USERS

5.1 Contacts

R.B. Stewart, Resources and Environment Section, Crop Production Division, Regional Development and Internal Affairs Branch, Agriculture Canada, Ottawa, Canada. K1A OC5.

J. Dumanski, Land Resources Research Institute, Research Branch, Agriculture Canada, Ottawa, Canada. K1A 065.
(e) Pocket calculator model for potatoes (Australia)

1. OBJECT OF METHOD

1.1 Objective

The general objectives are land evaluation for crop production and evaluation of production strategies and management tactics.

1.2 Title: Pocket-calendar model for predicting yield and development in potatoes.

2. DESCRIPTION OF METHOD

2.1 Output (expected results and accuracy)
The outputs are estimates of crop productivity or yield.

2.2 Description

In the model the crops are made sensitive to light, temperature and thermal regimes. In general the models are of the simulation type (process based) empirical/statistical functions are used where either understanding or the availability of input data is limiting. It is possible to run the models with daily, but also with weekly time steps.

2.3 Input data

Meteorological data: Daily or weekly values of: solar radiation, maximum and minimum temperature, precipitation and potential evaporation.

Crop data: Cultivar or broad phenological response class and sowing date.

Soil data: Extractable soil water in the profile.

2.4 Operational requirements (including computer requirement)

All model versions are written in FORTRAN 77 and developed on a VAX 11/750 computer system. Tape specifications: ASCII, 1600 bpi, fixed record length (80 char.), 50 records/block, 4,000 blocks/file.

2.5 Validation, application and limitations

The model is not used outside Australia. In most cases the constraints are a limited ability to handle important management variables other than empirically, e.g. population, spacing, geometry and limited ability to handle nutrient variation and supply.
3. VALIDATION/PROVEN USES

The model is validated.

4. REFERENCES


3.1.2.2 Comprehensive dynamic simulation models

(a) Physical crop production model

1. OBJECT OF METHOD

1.1 Objective: Assessment of the production level for various crops as determined by environmental conditions and management practices.

Title: The model of physical crop production.

2. DESCRIPTION OF METHOD

2.1 Output (expected results and accuracy)

Yield levels with and without irrigation per crop, soil type and crop management level and the associated inputs to achieve these yields.

2.2 Description

The model calculates dry matter production per ten-day period from leaf area index, precipitation, temperature, humidity, wind speed and absorbed solar radiation. Dry matter increment is partitioned into roots, leaves, stems and storage organs as a function of phenological development of the crop. The influence of water shortage is indicated through the ratio of actual and potential evaporation. Potential evaporation is calculated according to Penman. Actual evaporation follows from the water balance (rainfall, irrigation, run-off, soil evaporation, drainage, and upward movement from a ground water table). The influence of different nutrient levels is also indicated. Senescence of leaves is taken into account and also influence of weed competition and the effect of pest and diseases. Finally, the labour requirements are estimated at different levels of management.

2.3 Input data

<table>
<thead>
<tr>
<th>Meteorological data:</th>
<th>Daily or ten day averages of:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>precipitation, radiation, air temperature</td>
</tr>
<tr>
<td></td>
<td>air humidity, wind speed</td>
</tr>
</tbody>
</table>

| Crop data:          | Crop species ecophysiological characteristics. Length of growing cycle |

| Soil data:          | Soil physical properties      |
2.4 Operational requirements (including computer requirements)

Model installed on DEC-10 (written in Fortran 66. Several modules available for desk-top calculators. A version for hand held calculators (T.I. 30) has also been developed in tested.

2.5 Validity, limits imposed by basic concept, constraints in application

Validity is assessed by comparison of experimental data with model output. Data requirements are fairly heavy but can be adapted to availability of calculating equipment.

3. VALIDATION/PROVEN USES

Thailand - Bangladesh - Sierra Leone

The model was applied to generate information for national econometric and food system studies.

4. REFERENCES


5. AVAILABILITY

5.1 Contacts

Centre for Agrobiological Research (CABO) Dept. of Theoretical Production Ecology Agricultural University, P.O. Box 14 Wageningen, The Netherlands.
(b) **BACROS**

1. **OBJECT OF METHOD**

1.1 **Objective:** Detailed model of crop growth to evaluate results of equipment and help in the design of new ones, pinpoint gaps in the knowledge, assist in evaluating the results of change in plant properties

**Title:** Basic Crop Growth Simulator (BACROS)

2. **DESCRIPTION OF METHOD**

2.1 **Output (expected results and accuracy)**

Quantitative estimates of crop growth and production

2.2 **Description**

BACROS calculates the development of dry matter production of a crop under optimum supply of water and nutrients, without weed competition and in the absence of pests and diseases.

The processes of assimilation and respiration are modelled in detail. Assimilation is obtained from instantaneous values of solar radiation, taking into account leaf area index, spatial arrangement of the leaves and their optical properties. Respiration follows from the amount of biomass present, its phenological or chemical composition, the current rate of growth and the canopy temperature. Transpiration is obtained through a combination method from the heat balance of the crop.

Growth depends on the current assimilate supply, accumulated reserves and temperature

2.3 **Input data**

<table>
<thead>
<tr>
<th>Meteorological data:</th>
<th>Daily values-maximum-minimum temperatures, air humidity, wind speed, global radiation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crop data:</td>
<td>Plant measurements: photosynthesis-light response curve for individual leaves, stomatal resistance, cuticular resistance, chemical composition in the course of the growing season, (preferably leaf area index development since morphology is not treated)</td>
</tr>
</tbody>
</table>
2.4 Operational requirements (including computer requirements)

Written in CSSP (Continuous System Simulation Programme) and operational on computers to which this system is available (IBM 360, IBM 370, DEC-10). Can easily be installed on systems having access to a language of the CSSL group (Continuous System Simulation Languages).

2.5 Validity, limits imposed by basic concept, constraints in application

Applicable only under optimum growing conditions. Distribution of dry matter between vegetative and reproductive organs not accounted for. Crop data demands are fairly heavy.

3. VALIDATION/PROVEN USES

Model used on an individual plot scale

Validated extensively for different crops (maize, wheat, ry-grass, Rhodes grass) in different geographical regions (The Netherlands, USA, Israel, Peru). It is used primarily as a research tool.

4. REFERENCES


5. AVAILABILITY/SOURCES OF ASSISTANCE FOR FUTURE USERS

5.1 Contacts

Centre for Argobiological Research (CABO), Dept. of Theoretical Production Ecology, Agricultural University, P.O. Box 14, Wageningen, The Netherlands. (C.T. de Wit, J. Goudriaan, F.W.T. Penning de Vries, H. van Keulen, H.H. van Laar).
(c) **The POTATO Model**

1. **OBJECT OF METHOD**

1.1 Objective: To study:

(a) the integrative crop physiology of potato  
(b) the climate-crop interactions  
(c) the genotype evaluations  
(d) the management strategies

Title: Simulation of growth and yield of the potato crop.

2. **DESCRIPTION OF METHOD**

2.1 Output (expected results and accuracy)  
Quantitative estimates of potato growth and production

2.2 Description

The model is explanatory in nature and has a high degree of physiological and morphological detail. The model simulates the growth and development of all major organs under optimum supply of water and nutrients, without weed competition and in the absence of pests and diseases. The time step of the model is one hour. The canopy and soil climate are defined from input data. Transpiration and soil moisture rates are calculated first to give the rate change of plant water content. The rate of change in the plant assimilate pool is calculated from the photosynthesis, respiration and organ growth rates and from the rate of mobilization from senescing organs. Dry matter increment is partitioned into roots, leavens, stems and storage organs as a function of phenological development of the crop.

2.3 Input data

Meteorological data: Average daily air temperatures, air temperature amplitude, dew point. Daily totals of wind run at 2 m and radiation.

Crop data: Cultural information on plant density and the date of crop emergence and various physiological characteristics of the crop.

2.4 Operational requirements (including computer requirements)

Model installed on PDP II computer. The program is written in FORTRAN.
2.5 Validity, limits imposed by basic concept, constraints in application.

Validity is assessed by comparison of experimental data with model output. Overall agreement between simulated and field data was satisfactory. Sensitivity analysis as a guide for improvements in the model is also included.

3. VALIDATION/PROVEN USES

The model can be used as a research tool. The model was extended by P.A. Pinto to respond to different water regimes. It was tested against an early potato crop in Portugal, with good performance.

4. REFERENCES


(d) **SWACRO**

1. **OBJECT OF METHOD**

1.1 **Objective:** To determine the effects of soil and water management on potato production

1.2 **Title:** Soil water and crop yield model (SWACRO)

2. **DESCRIPTION OF METHOD**

2.1 **Output (expected results and accuracy)**

Quantitative estimates of crop growth and production as influence by water management techniques.

2.2 **Description**

The model consists of a soil water balance model SWATRE that describes the transient water flow in a heterogeneous soil-root system which is either or not under ground water influence. Maximum and actual growth rate are calculated with the model CROP (Fig.3). The date of emergence is calculated from established relationships between the heat sum from the time of planting (based on daily mean air temperatures) and the soil water pressure head in the seedbed. Soil cover and leaf area index vary with the development stage of the crop according to field established relationships. The same holds for the distribution of increase of dry matter production over shoot and tubers. The SWACRO model was further integrated with the model FLOWEX which computes the terms of the soil water balance of a non-cropped soil profile, in order to determine the effects of drainage on crop production (Fig.4).

2.3 **Input data**

**Meteorological data:** Daily values of precipitation solar radiation (or sunshine duration), maximum and minimum air temperatures, mean daily relative humidity and wind speed.

**Crop data:** Date of planting, relationships between soil cover and leaf area index as well as between the distribution of the increase in total dry matter production over shoot and tubers.

**Soil data:** Soil water retention and hydraulic conductivity curves for the different soil layers, drain depth and drain intensity and the initial soil water profile.
2.4 Operational requirements (including computer requirements)
Mini-or micro computers.

2.5 Validity, limits imposed by basic concept, constraints in application.

Validity was assessed by comparing the experimental data with model output, giving satisfactory results. In applying the model to different climatic conditions some of the parameters in the CROPR model might possibly need adaptation with respect to the local environmental conditions and potato varieties used. The effect of nitrogen fertilization on crop yield is not considered in the model.

3. VALIDATION/PROVEN USES

The model SWACRO that simulates the soil water balance and associated potato-tuber production has been applied to schedule time and amount of irrigation to estimate the optimal planting time to evaluate the effect of soil compaction on yield and to evaluate the effects of soil type and drainage on crop yield.

4. REFERENCES


---

*Fig. 3. Scheme of the SWACRO model consisting of the water balance model SWATRE (Soil Water Actual-Transpiration Extended) and the yield model CROP (Crop Production)*
Fig. 8: Flow chart of the integrated model approach for computing the influence of water management on yields of arable land.
(e) **A dynamic model of potato growth and development (USSR)**

1. **OBJECT OF METHOD**

1.1 **Objective:** To undertake quantitative assessment of past and expected agrometeorological conditions influencing yields, and to make consecutive yield forecasts (USSR).

**Title:** The productivity of Agro-ecosystems: A Dynamic Model.

2. **DESCRIPTION OF METHOD**

2.1 **Output (expected results and accuracy)**

Dynamics of phytomass, leaf area, final yield, soil moisture, evapotranspiration and other components of water balance.

2.2 **Description**

Model based on a system of differential equations describing the dynamics of phytomass (leaves, stems, roots, and reproductive organs) of plants. The system takes into account plant processes such as photosynthesis, respiration, growth, and development. The model includes a water-regime block which makes possible to compute soil moisture in 10-cm layers up to the depth of 150 cm. This considers the processes of infiltration of precipitation, movement of water in the soil, absorption of water by the root system, evaporation from the soil etc.

2.3 **Input data**

<table>
<thead>
<tr>
<th>Meteorological data:</th>
<th>Daily data: mean air temperature, precipitation humidity, duration of sunshine.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crop data:</td>
<td>Density and date of crop emergence</td>
</tr>
<tr>
<td>Soil data:</td>
<td>on the date of emergence: soil moisture for 10-cm layers to a depth of 150 cm</td>
</tr>
</tbody>
</table>

2.4 **Operational requirements (including computer requirements)**

Medium size computer necessary
2.5 Validity, limits imposed by basic concept, constraints in application

Model applicable for any field crop after the adjustment of its parameters, giving due consideration to new biometric information. Sets of model parameters for spring wheat, spring barley, winter wheat, and potato available.

3. VALIDATION/PROVEN USES

The model represents fairly well the inter-annual variability of final yield and has been tested and applied by the Hydrometeorological Service of the USSR. The accuracy of computation of water content is close to that of the observed values.

4. REFERENCES


Polevoy, A.N., 1983. Theory and calculation of crop productivity (Russ.). Lenigrad, Gidrometeorozdat, 175 pp

Polevoy, A.N., 1986. Simulation of potato crop production. A case study from USSR. In "Agrometeorology of Potato" To be published by WMO.


5. AVAILABILITY/SOURCES OF ASSISTANCE FOR FUTURE USERS

5.1 Contacts

O.D. Sirotenko, State Committee for Hydrometeorology and Control of National Environment, Hydrometeorological Service of USSR, 12 Pavlik Morozov Street, D-376 Moscow 123376, USSR.
3.2 CROP WATER REQUIREMENTS AND IRRIGATION

The crop water requirements for a 120 to 150 day crop are estimated between 500 to 700 mm depending on climate. Potato is relatively sensitive to soil water deficits. To optimize yields the total available soil water should not be depleted by more than 30 to 50%. The most sensitive stages to water stress conditions are the periods of tuber initiation and yield formation. However, varieties vary in their sensitivity to water deficit. Some varieties respond better to irrigation in the earlier part of the yield formation period, while others show a better response in the latter part of that period.

Information about the methods of estimation of water balance and actual crop evapotranspiration can be obtained from the models presented in the previous section. Here, some additional models are given.
3.2.1 FAO-Method

1. OBJECT OF METHOD

1.1 Objective: 1. To estimate crop water requirements from climatic data.

2. To determine the amount and frequency of irrigation.

3. To design irrigation projects.

4. To quantify the effect of water stress conditions to crop yield.

1.2 Titles (a) Guidelines for predicting crop water requirements

(b) Yield response to water

2. DESCRIPTION OF METHOD

2.1 Output (expected results and accuracy)

Estimation of reference crop evapotranspiration, crop evapotranspiration, actual evapotranspiration, scheduling of irrigation and estimation of yield reduction due to water stress conditions.

2.2 Description

Four methods can be used to estimate the reference crop evapotranspiration for grass, i.e. the Blaney-Criddle, Radiation, Penman and Pan evaporation method. The values of crop coefficients (Kc) are determined for various developmental stages of the crop (Table 6). The actual evapotranspiration is determined from the level of the available soil water which depends on the type of the soil, the rooting depth of the crop and the soil water depletion factor (p) which is a function of the crop characteristics (Table 6). Using rainfall data, the water balance during the growing season is estimated and the amount and frequency of irrigation is determined. In order to quantify the effect of water stress on yield a yield response factor (Ky) is required (Table 6).

2.3 Input data

Meteorological data: Daily temperature, humidity, wind speed, sunshine or radiation, pan A evaporation and precipitation
Crop data: Length of the growing period, rooting depth, crop coefficients and yield response factor

Soil data: Available soil water, soil water depletion fraction, groundwater contribution

Management data: Irrigation efficiency

2.4 Operational requirements (including computer requirements)
Micro-computer

2.5 Validity, limits imposed by basic concept, constraints in application
Separation of evapotranspiration into evaporation from the soil and transpiration could give more accurate results.

3. VALIDATION/PROVEN USES

The method is applied successfully by many countries.

4. REFERENCES


Additional References


Table 6

Crop coefficients (Kc) for use with grass reference ET0 and yield response factors (Ky)
(From FAO, Irrigation and Drainage Paper, 33)

<table>
<thead>
<tr>
<th>Stages: Initial Crop development</th>
<th>Mid-season</th>
<th>Late season</th>
<th>At harvest</th>
<th>Total growing period</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Kc</strong></td>
<td>0.4-0.5</td>
<td>0.7-0.8</td>
<td>1.05-1.2</td>
<td>0.85-0.95</td>
</tr>
<tr>
<td><strong>Ky</strong></td>
<td>0.45</td>
<td>0.8</td>
<td>0.7</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Basal evapotranspiration crop coefficients (Kcb) for use with alfalfa

Reference evapotranspiration (From Wright, 1982). Note that there are some differences in the formulas to calculate ET0 using the four methods comparing with grass ET0.

(a) Time from planting to effective cover (%)

<table>
<thead>
<tr>
<th>%</th>
<th>10</th>
<th>20</th>
<th>30</th>
<th>40</th>
<th>50</th>
<th>60</th>
<th>70</th>
<th>80</th>
<th>90</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kcb</td>
<td>0.15</td>
<td>0.15</td>
<td>0.15</td>
<td>0.21</td>
<td>0.35</td>
<td>0.45</td>
<td>0.60</td>
<td>0.72</td>
<td>0.78</td>
<td>0.80</td>
</tr>
</tbody>
</table>

(b) Days after effective cover

<table>
<thead>
<tr>
<th>days</th>
<th>10</th>
<th>20</th>
<th>30</th>
<th>40</th>
<th>50</th>
<th>60</th>
<th>70</th>
<th>80</th>
<th>90</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kcb</td>
<td>0.80</td>
<td>0.80</td>
<td>0.75</td>
<td>0.74</td>
<td>0.73</td>
<td>0.72</td>
<td>0.70</td>
<td>0.50</td>
<td>0.25</td>
<td>0.20</td>
</tr>
</tbody>
</table>

Soil depletion faction (p) for potato as a function of crop evapotranspiration (From, Irr. and drainage paper, 33)

<table>
<thead>
<tr>
<th>ETcrop (mm/day)</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>p</td>
<td>0.50</td>
<td>0.425</td>
<td>0.35</td>
<td>0.30</td>
<td>0.25</td>
<td>0.225</td>
<td>0.20</td>
<td>0.20</td>
<td>0.175</td>
</tr>
</tbody>
</table>
3.2.2 MORECS (England)

1. OBJECT OF METHOD

1.1 Objective: To provide estimates of weekly and monthly evaporation and soil moisture deficit in the form of averages over 40x40 km grid squares using daily synoptic data as input.

1.2 Title: Meteorological office Rainfall and Evaporation Calculation System (MORECS)

2. DESCRIPTION OF METHOD

2.1 Output (expected results and accuracy)

Weekly or fortnightly issues of maps or tables showing for each grid square and for 3 different types of soils values of PE (potential evapotranspiration), AE (Actual evapotranspiration), SMD (Soil moisture deficit), HER (Hydrologically effective rainfall) for 13 crops/surface types, and square values of the 5 basic meteorological variables (sunshine, temperature, vapour pressure, wind speed and rainfall.

Generally, there are five options available which provide data in both tabular and graphical (map) form depending of the requirements of the users.

2.2 Description

The system has five main components:

1. Data collection, interpolation and averaging.

2. Data analysis to obtain evaporative demand over each grid square. The daily potential evapotranspiration (PE) is calculated for a range of surface covers from bare soil to forest using a modified form of the Penman-Monteith combination equation.

3. The actual evapotranspiration (AE) is estimated by progressively reducing the rate of water loss from the potential value to zero as the available soil moisture decreases from 60% of its maximum value to zero.


5. Data output.
2.3 Input data

Meteorological data: Daily maximum and minimum temperatures, daily totals of rainfall and sunshine duration and the average daily vapour pressure obtained either by averaging observations (at 03, 09, 15 and 21 GMT) or from the single 0900 GMT value.

Crop data: Crop developmental stages, effective crop heights, maximum LAI, crop resistances for dense green crops freely supplied with water.

Soil data: Available water capacities for 3 types of soils and different rooting depths of crops.

2.4 Operational requirements (including computer requirements)
Main-frame computers.

2.5 Validity, limits imposed by basic concept, constraints in application.

Correct specification of surface resistance ($r_s$) is crucial to the satisfactory running of MORECS. Some allowance for the effect of age and soil moisture on $r_s$ is included in the model.

3. VALIDATION/PROVEN USES

Comparison of MORECS output data with neutron probe soil moisture deficit data showed good agreement. The output could assist to determine leaching of nutrients or to assess short-term irrigation requirements.

4. REFERENCES


3.2.3 **Irriguide (United Kingdom)**

1. **OBJECT OF METHOD**

1.1 Objective: To guide users on irrigation scheduling.

2. **DESCRIPTION OF METHOD**

2.1 Output (expected results and accuracy)
It calculates the daily soil moisture deficits (SMD) and gives advice on when each field will need to be irrigated.

2.2 Description

The program is available for a wide range of arable, fruit, grass, vegetable and nursery stock crops. It is a flexible system that allows different critical soil moisture deficits to be used at different crop growth stages and it takes account of varying crop cover in different crops and irrigated areas. It also takes account of different rooting depths and cultivations carried out in the growing season. Irriguide reports include a seven-day forecasts of the moisture status of each field based on the local weather forecast.

2.3 Input data

**Meteorological data:** Daily forecasts rainfall and 3-day rainfall

**Crop data:** Type of crop and time of growing

**Soil data:** Soil type

**Management data:** Irrigation data, Basic field and site details

2.4 Operational requirements (including computer requirements)
Micro-computer of mini-computers.

2.5 Validity, limits imposed by basic concept, constraints in application.

Daily rainfall and irrigation data should be kept by the farmer on special sheets.

3. **Contacts**

Agromet Section (Met 0 3C)
Meteorological Office
London Road
Bracknell
Berkshire RG12 2SZ
3.2.4 Long term Irrigation Planning Program (IPP) (United Kingdom)

1. OBJECT OF METHOD

1.1 Objective: To calculate water requirements in both long and short term.

2. DESCRIPTION OF METHOD

2.1 Output (expected results and accuracy)

The program provides an irrigation plan for a particular farm. The farm is divided up into a number of fields and the program provides the following information.

(i) the dates on which water was required and the amount applied (in mm),

(ii) a year-by-year breakdown of:
   (a) the total water required,
   (b) the number of applications in the year,
   (c) the dates of the first and last applications,
   (d) the minimum period (in days) between successive applications,
   (e) run off from April - September

(iii) the number of times a given period between applications occurs, i.e. a frequency distribution of the application interval (this is supplied for each year in turn),

(iv) monthly totals of the water requirement,

(v) yearly totals of the water requirement.

2.2 Description

The method is designed to evaluate any specified irrigation schedule. To produce monthly and annual estimates of irrigation need several crop characteristics, soil available water capacity (AWC) and locally adjusted rainfall data are required.

2.3 Input Data

The geographical location of the farm is required. The following data are supplied for each field in turn on the farm, for up to a maximum of 14 fields:
(i) the size of the field (in ha),

(ii) the soil type (in one of three classes corresponding to low, medium or high available water capacity),

(iii) the crop(s) that are grown in the field. Often there will be one crop but there can be from 2 to 5 crops in rotation. For each crop estimates are required of,

(1) the planting/sowing date, the date of 25% cover, the date of 75% cover, the date of senescence or harvest,

(2) the 'irrigation plan'. This is in a number of 'stages'. Each 'stage' is of the form:

(a) date on which irrigation commences,
(b) SMD at which water is applied,
(c) amount of water applied when threshold SMD is reached,
(d) date on which irrigation ends.

The user supplies the number of irrigation stages (up to a maximum of 5) that are required to describe the irrigation plan for the crop. Often one stage is sufficient.

2.4 Operational requirements (including computer requirements)
Main-frame computer

2.5 Validity, limits imposed by basic concept, constraints in application

The average farm values of rainfall are adjusted to the nearly meteorological station. The bands specifying low, medium and high available water capacities are arbitrary and in the case of medium AWC's extremely large. Physiologically important crop parameters such as height, leaf area index and rooting depth must be incorporated in the program instead of the concept of "root constant". It is assumed that runoff occurs instantaneously through the soil profile.

3. VALIDITY/PROVEN USES

The predicted irrigation need for main crop potatoes was in reasonable agreement with experimental data. Cost/benefit ratios can be calculated with this model.
4. REFERENCES


5. Contacts

Meteorological Office Headquarters
Agromet Section (Met 0 3C)
Meteorological Office
London Road
Bracknell
Berkshire RG12 2SZ
United Kingdom
3.2.5 Irrigation management services (United Kingdom)

1. OBJECT OF METHOD

1.1 Objective: To provide arable (especially potato) farmers with weekly advice on when and how much water to apply to crops by irrigation.

1.2 Title: Irrigation Management Services

2. DESCRIPTION OF METHOD

2.1 Output:
1. Water balance (including crop cover and root depth).
2. Forecast water balance for next 10 days.
3. Advice on when to irrigate and how much to apply.

2.2 Description: The method is based on a computerized water balance model. It considers evaporation from bare soil, crop cover development, limiting soil water deficits and root growth.

The model is intended for use alongside direct measurements of soil water content by neutron probe, but can be used alone.

Can be run on historical data to determine irrigation requirements.

2.3 Input Data:

Meteorological: Mean temperature and humidity, wind run, sunshine on solar radiation on daily basis

Crop data: Crop type and variety, date of panting and emergence, estimated maximum rooting depth.

Soil data: Total available water capacity in root zone.

Management data: Nature of irrigation equipment, design application rates, systems capacity

2.4 Operation requirements: IBM compatible minicomputer.

2.5 Validity, limits imposed by basic concept, constraints in application: Application to light textured soils with deep water table.

3. VALIDATION /PROVEN USES

Model predictions validated against 4 years of field water content measurements by neutron probe and used as a research tool.
4. REFERENCES


5. AVAILABILITY/SOURCES OF ASSISTANCE FOR FUTURE USERS

From Irrigation management services, Silsoe College

5.1 Contacts

T. M. Hess & M.K. V. Carr
College, Silsoe, Bedford, MK45 4DT
3.2.6 Estimation of water and irrigation requirements of potato (Hungary)

1. OBJECT OF METHOD

1.1 Objective:
1. To estimate the water requirement of potato
2. To estimate the actual evapotranspiration of potato
3. To determine the irrigation requirement as the difference between the water requirement and actual evapotranspiration

2. DESCRIPTION OF METHOD

2.1 Output:
Estimation of water requirement, actual evapotranspiration, amount and time of irrigation and soil moisture content

2.2 Description: The water requirement is estimated as a product of \( k \cdot PE \) where \( k \) are the crop coefficients and PE potential evapotranspiration. The actual evapotranspiration is estimated from the values of potential evapotranspiration, the level of the available soil moisture content and a crop factor \( b \). The irrigation requirement is calculated as the difference of water requirement and actual evapotranspiration. The method was developed by Antal (1968).

2.3 Input Data:

Meteorological: Air temperature, saturation deficit, precipitation (daily, five-days, ten-days or monthly mean values).

Crop data: Crop coefficients \( (k) \) and the factor \( (b) \). These are determined on the basis of measurements.

Soil data: Available soil water capacity, available soil water content at the beginning of the growing season, in the root zone.

2.4 Operation requirements: Micro-computer

2.5 Validity, limits imposed by basic concept, constraints in application: Validity was checked by comparison with experimental results.

3. VALIDATION /PROVEN USES

The method is used successfully by Hungarian cooperative farms.
4. REFERENCES


5. AVAILABILITY/SOURCES OF ASSISTANCE FOR FUTURE USERS

5.1 Contacts

Agrometeorological Department, Central Meteorological Institute, Meteorological Service of the Hungarian People's Republic, H-1525 Budapest, P.O.B. 38. Hungary
3.2.7 Irrigation using pan A evaporation data (Cyprus)

1. OBJECT OF METHOD

1.1 Objective: To determine the amount and frequency of irrigation of potatoes by sprinklers or trickles on the basis of pan evaporation.

2. DESCRIPTION OF METHOD

2.1 Output (expected results and accuracy)

Time of irrigation and amount of water required.

2.2 Description

Over the main irrigation season the amount of water required for sprinkler-irrigation was found to be 0.7-0.8 of pan A evaporation. For trickle-irrigated plants 20% more water is required. With regard the frequency of irrigation the method suggests that irrigating by sprinkler whenever 25 mm of pan evaporation have been accumulated was sufficient to maximise yield production.

2.3 Input data

Meteorological data: Daily rainfall and pan A evaporation

Crop data: Time of tuber initiation

2.4 Operational requirements (including computer requirements)

Daily water balance sheet method.

2.5 Validity, limits imposed by basic concept, constraints in application

Validity was assessed by comparison the results with experimental data.

3. VALIDITY/PROVEN USES

The method is applied successfully by many farmers.

4. REFERENCES

3.3 Forecasting systems and simulation models of pests and diseases of potato

The rates of development or spread of certain plant diseases are known to be directly linked to weather. Useful agrometeorological information, advice and warnings for crop protection is now produced successfully by many countries.

Potato late blight (Phytophthora infestans) is the main focus in many countries of their warning and information systems (Table 7). Several forecasting systems, based on general weather criteria, are in use by many countries to identify weather conditions favourable to the development and spread of the disease. These systems indicate critical periods and they are not designed to simulate the progress of the disease development. However, they serve as a good guide for the grower. Examples of such systems are: the Dutch, Beaumont's Smith, Irish, Norwegian, Poland and Finland rules, as well as the SYMPHYT model developed by the German Democratic Republic and the warning system developed in the United States known as BLITECAST.

Some countries use "negative forecasting" systems which predict the earliest possible date the disease may occur, i.e. the length of the period free from pests and diseases. The common point of the said systems is that they usually indicate the timing of the initial spray application and the frequency of sprays during the season.

Furthermore, improvements in biological data acquisition and processing systems along with advances in modelling techniques, have permitted the employment of plant disease forecasting to facilitate pest management control (Jeger, 1983, Rapilly and Payen, 1986). An excellent review of the conditions associated with late blight outbreaks throughout the world is given by Cox and Large (1960).

The survey also includes forecasting methods of various pests and diseases such as potato early blight (Alternaria solani), the population dynamics of potato cyst-nematode (Globodera pallida) and the appearance of various potato aphids. Details about the meteorology and the Colorado potato beetle are given by Hurst (1975) (Table 8).

The problem of production and dissemination of agrometeorological information and warnings for pests and disease control is discussed in detail by Thompson (1986). Details about the use of meteorological data in plant disease warning schemes in England with special reference on the way of dissemination of the agrometeorological information is given by Roe (1984).

Examples of warning systems or simulation models, concerning potato pests and diseases, which are in operational use in various countries are given below. Some of these systems were in operational use for some time and were abandoned in favour of a more efficient one. In order to complete the list of the warning systems used in Europe, a reference will be made on those systems, which are in operational use in countries outside the region (e.g. BLITECAST, LATEBLIGHT etc.).
REFERENCES


Hurst, G.W., 1975. Meteorology and the Colorado potato beetle. WMO-No.391, Technical Note No. 137.


**TABLE 7**

**POTATO LATE BLIGHT WARNING SYSTEMS**

(a) Warning Systems based on several weather criteria

<table>
<thead>
<tr>
<th>Country</th>
<th>Name of warning or information system</th>
<th>Meteorological data required</th>
<th>Crop data required</th>
<th>Agrometeorological information (Method)</th>
<th>Output form of index and system</th>
<th>Performance of the system</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Netherlands</td>
<td>Dutch or van Everdingen rules</td>
<td>Dew, Minimum temp, Cloudiness, Rainfall</td>
<td>Date of green line stage or the time when the crop height of 20 cm is reached</td>
<td>(a)Night dew &gt;4 hrs (b)In&gt;10 C (c)Mean cloudiness exceeding 8/10 in the next day (d)R&gt;0.1 mm in the day following the dew-night</td>
<td>Critical periods are identified</td>
<td>Difficult to apply rules(a) and(c). In the recent years warnings are issued based on the relationships between the critical periods and synoptic weather conditions</td>
<td>Van Everdingen 1933</td>
</tr>
<tr>
<td>England</td>
<td>Beaumont's rules</td>
<td>Hourly observations of the concept of zero date for each area and cultivar</td>
<td>Establishaent</td>
<td>A period of 48 hours with T&gt;10 C and RH&gt;75%. A &quot;near critical period&quot; is defined when RH&gt;75% in 46 out of 48 hourly observations</td>
<td>Critical periods are identified</td>
<td>Beaumont, 1947; Grainger, 1950.</td>
<td></td>
</tr>
<tr>
<td>England</td>
<td>Smith rules</td>
<td>Hourly data of air temperature and relative humidity</td>
<td>Starting date of calculating Smith periods is the &quot;zero date&quot;</td>
<td>A period of 48 hours with T&gt;10 C and RH&gt;90% on at least 11 hours in each day. A &quot;near miss&quot; occurs when RH&gt;90% for 10 hrs</td>
<td>Critical periods are identified</td>
<td>When the disease outbreaks are unusually early the method fails and when outbreaks are unusually late premature warnings are given</td>
<td>Smith, 1956; Sparks, 1980</td>
</tr>
<tr>
<td>Country</td>
<td>Name of warning or information system</td>
<td>Meteorological data required</td>
<td>Crop data required</td>
<td>Agrometeorological information (Method)</td>
<td>Output</td>
<td>Performance of the system</td>
<td>References</td>
</tr>
<tr>
<td>-----------</td>
<td>-------------------------------------</td>
<td>-----------------------------</td>
<td>---------------------</td>
<td>----------------------------------------</td>
<td>--------</td>
<td>--------------------------</td>
<td>-------------</td>
</tr>
<tr>
<td>Ireland</td>
<td>Irish rules</td>
<td>Hourly data or air tempearture relative humidity and precipitation. The monitor of blight weather starts from mid-April until September</td>
<td>Effective blight hours (EBH) are calculated when T&gt;10°C and RH&gt;90%</td>
<td>Blight-weather spells are determined based on the accumulated EBH and rainfall</td>
<td>The method is applied successfully in Ireland. It can be used for both day to day operations and planning purposes</td>
<td>Bourke, 1955; Keane, 1982.</td>
<td></td>
</tr>
<tr>
<td>Norway</td>
<td>Norwegian rules</td>
<td>Maximum and Minimum temp. development Relative humidity, Rainfall. The Monitoring starts from June until September</td>
<td>(a) 17&lt;Tx&gt;24°C (b) In&gt;10°C (c) RH at 1200&gt;75% (d) R&gt;0.1 mm</td>
<td>The parameters involve are calculated daily and printed out daily in the weather statistics as: warning A for 5 day, B for 2 consecutive days up to 5 for 5 consecutive day</td>
<td>The method is successfully applied in this country</td>
<td>Forsund, 1983</td>
<td></td>
</tr>
<tr>
<td>Country</td>
<td>Name of warning or information system</td>
<td>Meteorological data required</td>
<td>Crop data required</td>
<td>Agrometeorological information (Method)</td>
<td>Output Index &amp; form of output</td>
<td>Performance of the system</td>
<td>References</td>
</tr>
<tr>
<td>-----------------------</td>
<td>--------------------------------------</td>
<td>-----------------------------</td>
<td>--------------------</td>
<td>----------------------------------------</td>
<td>-------------------------------</td>
<td>------------------------------------------------------------------------------------------</td>
<td>-----------------------------</td>
</tr>
<tr>
<td>Poland</td>
<td>Poland rules</td>
<td>Mean relative humidity in June and August. Total rainfall and number of raindays above 0.1 mm in July</td>
<td></td>
<td>Regression analysis between blight intensity and the input meteorological parameters for selected soil type</td>
<td>Hazard index or blight intensity index</td>
<td>The mean effect of the climate on the occurrence of potato blight in the region can be evaluated</td>
<td>Utrata, 1980</td>
</tr>
<tr>
<td>Finland</td>
<td>Finland rules</td>
<td>Hourly temperatures and relative humidity</td>
<td>Blight sensitivity of the variety</td>
<td>A risk rate is estimated daily according to the number of hours &gt;90% and the average air temperature during these periods</td>
<td>Daily risk rate estimation with advice for spraying</td>
<td>The method is applied successfully although most farmers are spraying on routine basis against the disease</td>
<td></td>
</tr>
<tr>
<td>German Democratic Republic</td>
<td>SIMPHYT I SIMPHYT II</td>
<td>Rainfall and Temperature</td>
<td>SIMPHYT I describes the infection pressure at the beginning of an epidemic and SIMPHYT II schedules the subsequent spray applications</td>
<td>Disease severity and recommendations for spraying</td>
<td>3-4 fewer spray applications during the growing season</td>
<td></td>
<td>Kluge and Gutsche, 1983; 1984</td>
</tr>
<tr>
<td>Country</td>
<td>Name of warning or information system</td>
<td>Meteorological data required</td>
<td>Crop data required</td>
<td>Agrometeorological information (Method)</td>
<td>Output Index &amp; form of output</td>
<td>Performance of the system</td>
<td>References</td>
</tr>
<tr>
<td>-------------</td>
<td>--------------------------------------</td>
<td>-----------------------------</td>
<td>--------------------</td>
<td>----------------------------------------</td>
<td>------------------------------</td>
<td>---------------------------</td>
<td>---------------------</td>
</tr>
<tr>
<td>Portugal</td>
<td>Divoux shachus with Guntz scale</td>
<td>Daily mean of temperature and Relative humidity</td>
<td>Number of hours of periods above 12 h with {air temp &gt;10°C (a)} and {Rel. Hum. &gt; 90%}</td>
<td>Critical periods are identified and treatments are applied when periods of (a) are above 18/24 h</td>
<td>The method works well for normal conditions of the disease development</td>
<td>Divoux 1963, 1964; Guntz, M. 1959</td>
<td></td>
</tr>
<tr>
<td>United States</td>
<td>Hyre System</td>
<td>Max. and Min. temper., Daily Rainfall</td>
<td>A &quot;blight-favourable day&quot; is considered when the 5-day average temp. is below 25.5°C and the total rainfall of the last 10-day period is &gt;30 mm. Days with Tn&lt;7.2°C are considered unfavourable</td>
<td>The initial day of late blight is forecast 7-14 days after the first occurrence of 10 consecutive blight favourable days</td>
<td>Timely availability of the &quot;blight favourable days&quot; is required</td>
<td>Hyre, 1954</td>
<td></td>
</tr>
<tr>
<td>Country</td>
<td>Name of warning or information system</td>
<td>Meteorological data required</td>
<td>Crop data required</td>
<td>Agrometeorological information (Method)</td>
<td>Output</td>
<td>Performance of the system</td>
<td>References</td>
</tr>
<tr>
<td>------------</td>
<td>---------------------------------------</td>
<td>-----------------------------</td>
<td>--------------------</td>
<td>----------------------------------------</td>
<td>--------</td>
<td>---------------------------</td>
<td>-----------------------------</td>
</tr>
<tr>
<td>United States</td>
<td>Wallin's system</td>
<td>Hourly values of temperature and relative humidity</td>
<td>Crop emergence</td>
<td>Estimation of &quot;severity values&quot; depending on the duration of relative humidity &gt;90% and average temperature during these periods</td>
<td>Initial appearance of potato late blight is predicted after the accumulation of 18-20 &quot;severity values&quot; and further occurrences are predicted after the accumulation of 5 &quot;severity values&quot;</td>
<td>The method issued for over 15 years in United States with good results</td>
<td>Krause et al., 1975; Mackenzie, 1981; Wallin, 1962</td>
</tr>
<tr>
<td>Country</td>
<td>Name of warning or information system</td>
<td>Meteorological data required</td>
<td>Crop data required</td>
<td>Agrometeorological information (Method)</td>
<td>Output Index &amp; form of output</td>
<td>Performance of the system</td>
<td>References</td>
</tr>
<tr>
<td>--------------</td>
<td>--------------------------------------</td>
<td>-------------------------------</td>
<td>--------------------</td>
<td>----------------------------------------</td>
<td>-------------------------------</td>
<td>--------------------------</td>
<td>--------------------------</td>
</tr>
<tr>
<td>United States</td>
<td>BLITECAST</td>
<td>Maximum and Minimum temp.</td>
<td>a) Green-row stage</td>
<td>Synthesis of weather conditions</td>
<td>Summary of weather conditions</td>
<td>1. In moderately favourable microclimates</td>
<td>Fohner et al., 1984; Fry and Fohner, 1985; Fry et al., 1983; Krause et al., 1975; Mackenzie, 1981; Nulter &amp; MacHardy, 1980; Pscheidt and Stevenson, 1986; Stevenson,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number of hrs with RH&gt;90%</td>
<td>b) Sensitivity of the cultivar</td>
<td>It forecasts the initial occurrence of the disease and schedules subsequent applications</td>
<td>and spray recommendations</td>
<td>Blitecast resulted in an average 1.3 fewer applications of fungicide than the 7-day interval while in unfavourable microclimates resulted 3-4 fewer applications</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Daily Daily rainfall</td>
<td></td>
<td></td>
<td></td>
<td>2. Blitecast was successful in predicting the initial occurrence, but not in the timing of spray recommendations</td>
<td></td>
</tr>
</tbody>
</table>


(b) Negative Forecasting Systems

<table>
<thead>
<tr>
<th>Country</th>
<th>Name of warning or information system</th>
<th>Meteorological data required</th>
<th>Crop data required</th>
<th>Agrometeorological information (Method)</th>
<th>Output Index &amp; form of output</th>
<th>Performance of the system</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Federal Republic of Germany</td>
<td>PHYPTRG</td>
<td>Hourly values of temperature and relative humidity and precipitation</td>
<td>Date of crop emergence</td>
<td>The hourly values of the meteorological elements are used to compute the Weekly and Total Phytophthora index (WPI, TPI). The beginning of an epidemic disease is considered to start when TPI&gt;150</td>
<td>1. Weekly and Total Phytophthora indices (WPI, TPI). 2. Estimating the date when TPI=150</td>
<td>The system is applied successfully in the referred countries</td>
<td>Dannecker, 1987; Van Eimern, 1964; Beger, 1986; Schiessendoppler, 1980; 1986; Schiff and Schroder, 1984; Schroder, 1972; 1983 Schroder and Ullrich, 1965; 1966; 1967 Ullrich and Schroeder, 1966; Wagen, 1980</td>
</tr>
<tr>
<td>2. Switzerland</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Austria</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Denmark</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Yugoslavia</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Israel</td>
<td>Negative Forecasting System</td>
<td>Daily maximum and minimum temperatures</td>
<td>Date of planting</td>
<td>The disease free-period is linearly related to the mean daily temperature during the first 30-days after planting</td>
<td>The estimated disease free-period and the occurrence in Israel of potato late blight</td>
<td>The system is applied successfully</td>
<td>Lomas, 1983; Lomas et al., 1971</td>
</tr>
</tbody>
</table>
### Warning Systems based on simulation models

<table>
<thead>
<tr>
<th>Country</th>
<th>Name of warning or information system</th>
<th>Meteorological data required</th>
<th>Crop data required</th>
<th>Agrometeorological information (Method)</th>
<th>Output form of index</th>
<th>Performance of the system</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>England</td>
<td>BLIGHT</td>
<td>Hourly values of temperature, dew point, precipitation and the presence or not of fog</td>
<td>Crop development stages: 1. individual plants, 2. foliage meeting in but not across rows, 3. foliage meeting in and across rows, 4. postative stems with erect side branches</td>
<td>The stages of the disease which are explicitly modelled by BLIGHT are: growth of spores, survival of spores, incubation of infections and formation and senescence of lesions.</td>
<td>The possible magnitude of new infections each day is given by the parameter INFECT which takes the values of $0, 1, 2, 3$ (moderate) or $3$ (heavy)</td>
<td>Tests showed that the majority of predicted outbreak dates were within ±10 days of the observed dates. The model can not be used to calculate the development of blight on damps and earlies.</td>
<td>Hume, 1985; Rue, 1984; Sparks, 1980; 1984a, 1984b; Wass, 1984</td>
</tr>
<tr>
<td>United States</td>
<td>LATEBLIGHT</td>
<td>Daily values of maximum and minimum temp. and rainfall Number of hours of relative humidity exceeding 90% and average temperature during these periods and leaf wetness records</td>
<td>Crop cultivar and its sensitivity to P. infestans</td>
<td>The model simulates the effects of environment, fungicide, and crop resistance on P. infestans in potato foliage</td>
<td>The model does not describe the overwintering of the pathogen or the production of initial inoculum and therefore its use in specific fields is limited. The spatial dynamics of epidemic development are not considered. Certain features of fungicide deposition and loss are oversimplified.</td>
<td>Bruhn and Fry, 1981; 1982a, 1982b; Bruhn et al., 1980</td>
<td></td>
</tr>
<tr>
<td>Country</td>
<td>Name of warning or information system</td>
<td>Meteorological data required</td>
<td>Crop data required</td>
<td>Agrometeorological information (Method)</td>
<td>Output Index &amp; form of output</td>
<td>Performance of the system</td>
<td>References</td>
</tr>
<tr>
<td>-----------</td>
<td>--------------------------------------</td>
<td>-----------------------------</td>
<td>--------------------</td>
<td>----------------------------------------</td>
<td>------------------------------</td>
<td>---------------------------</td>
<td>----------------------------------</td>
</tr>
<tr>
<td>United States</td>
<td>Potato Disease Management (PDM)</td>
<td>Hourly temperature and relative humidity, leaf wetness records and daily rainfall totals</td>
<td>a) Green-row stage</td>
<td>A combination of the FAST and BLITECAST models b) Information about the sensitivity of the cultivar</td>
<td>Date of initial occurrence of the disease and subsequent recommendations for fungicide applications</td>
<td>The model is applied successfully in Wisconsin</td>
<td>Pscheidt and Stevenson, 1986; University of Wisconsin - Users Guide, 1986</td>
</tr>
<tr>
<td>Cyprus</td>
<td>Simulation model</td>
<td>Temperature, relative humidity, rainfall and wind speed at 3 hourly interval</td>
<td>Number of plants/km², LAI</td>
<td>The stages of disease which are modelled are: production of spores and lesions, deposition of spores, survival of spores, spore infections, incubation of infections, and foliage destruction</td>
<td>Number of days required to destroy the foliage of the crop</td>
<td>The model requires validation in order to be used operationally</td>
<td>Michaelides, 1985</td>
</tr>
<tr>
<td>Country</td>
<td>Name of warning or information system</td>
<td>Meteorological data required</td>
<td>Crop data required</td>
<td>Agrometeorological information (Method)</td>
<td>Output Index &amp; form of output</td>
<td>Performance of the system</td>
<td>References</td>
</tr>
<tr>
<td>---------</td>
<td>-------------------------------------</td>
<td>-----------------------------</td>
<td>-------------------</td>
<td>-----------------------------------------</td>
<td>-----------------------------</td>
<td>---------------------------</td>
<td>------------</td>
</tr>
<tr>
<td>United States</td>
<td>Growing degree-days (GDD)</td>
<td>Daily maximum and minimum temperatures</td>
<td>Date of crop emergence</td>
<td>Weekly sprays are initiated from crop emergence when GDD&gt;1000 cd and above 7°C have been accumulated</td>
<td>Date when GDD&gt;1000 cd</td>
<td>On average 3 fewer fungicide applications than the conventional programme are required</td>
<td>Pscheidt and Stevenson, 1986</td>
</tr>
<tr>
<td>United States</td>
<td>Physiological P-Days</td>
<td>Hourly temperature data as well as maximum and minimum temperatures</td>
<td>Date of crop emergence</td>
<td>Weekly sprays are initiated from crop emergence when P-Days&gt;300</td>
<td>Date when P-Days&gt;300</td>
<td>On average 2 fewer sprays than the conventional programme are required</td>
<td>Pscheidt and Stevenson, 1986</td>
</tr>
<tr>
<td>United States</td>
<td>PAST This model is past of the Potato Disease Management (PDM) model which is used for both early and late potato blight</td>
<td>Maximum and minimum temperatures</td>
<td>Date of crop emergence</td>
<td>Initial spray is applied when 35 severity values (based on leaf wetness and relative humidity, Leaf wetness records and daily rainfall) have been accumulated. Subsequent sprays are applied at 7 day intervals when &gt;11 severity values have been accumulated in the last 7 days</td>
<td>Dates when certain amount of severity or rating values have been accumulated</td>
<td>Pscheidt and Stevenson 1986; Madden et al., 1978</td>
<td></td>
</tr>
</tbody>
</table>
b) Other pests and diseases

<table>
<thead>
<tr>
<th>Country</th>
<th>Name of warning or information system</th>
<th>Meteorological data required</th>
<th>Crop data required</th>
<th>Agrometeorological information (Method)</th>
<th>Output Index &amp; form of output</th>
<th>Performance of the system</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Netherlands</td>
<td>Potato cyst-nematode model</td>
<td>Air and soil temperatures at 30 cm depth and solar radiation</td>
<td>Crop development stages and paracitic stages</td>
<td>The models is a combination of the growth model SUCROS and a model which simulates the changing number of individual nematodes</td>
<td>Number of cyst-nematode population and yield losses</td>
<td>It is applied satisfactorily in the Netherlands</td>
<td>van Keulen et al., 1982; Ward et al., 1983; Schans J., 1986</td>
</tr>
</tbody>
</table>
3.3.1 Simple warning systems

3.3.1.1 Dutch rules

Four weather conditions must be fulfilled for an appearance of the potato blight within 10 or 14 days:

(a) At least 4 hours of night dew;
(b) A minimum temperature above 10°C;
(c) Mean cloudiness on the following day exceeding 8/10, and
(d) At least 0.1 mm of rain in the 24 hours following the dew night.

In 1948 these rules, which were difficult to apply satisfactorily, especially rules (a) and (c), were abandoned in favour of a simpler temperature-humidity rule. The method of predicting outbreaks of blight by a temperature-humidity rule was first used by Beaumont for the Southwest of England.

In 1965 it was decided to remedy the drawbacks as far as possible and warnings are issued based on weather predictions. The service is since executed by means of a close cooperation of the national meteorological service and the agricultural advisory service. The service started with an advise for a first spraying of the vulnerable cultivars grown for vegetable production, irrespective of the weather or the presence of the disease. The starting sign is the phenoology of the crop. Until shortly this was the green line stage, while in recent years the first treatment is executed at a crop height of 20 cm. In potatoes grown for starch production the first treatment is given upon the first infections reported from the field.

Messages are disseminated by radio when both forecasted weather and the epidemiological situation give rise to expect serious infections.

References

3.3.1.2 **Beaumont's rules**

Beaumont's rules introduce the concept of the "critical period" which generally proceeds the first outbreak of potato blight by 7 to 21 days. The "critical period" is defined as a period of at least 48 hours with a temperature exceeding 10°C and a relative humidity exceeding 75%. An element of controlled elasticity was introduced by the concept of a "near-critical period" during which relative humidity >75% on at least 46 out of 48 hourly observations. Furthermore, the concept of "zero date", defined by Grainger (1950) was applied to the Beaumont period which establishes, from experience, the earliest date of appearance of the disease in different areas. Weather conditions prior to this date would be ignored. The Beaumont period was used for operational blight forecasting in England from 1950 to 1975 when it was replaced by the Smith period.

**References**


3.3.1.3 **Smith rules**

The Smith periods are used for operational purposes in England. A model introduced by Sparks (1980) was also used operationally for several years to compile weekly disease reports. A Smith period is defined as a period of 48 hours with:

(a) Air temperature >10°C; and
(b) Relative humidity >90% on at least 11 hours in each day.

A "near miss" occurs when one or both of such days has only 10 hours of high humidity (>90%). The "zero date" is used as a starting date for counting the Smith periods. This is rather arbitrary and would be expected to vary from year to year and over the country. When the disease outbreaks are unusually early the method fails to give an adequate warning and similarly when outbreaks are usually late premature warnings are given.

**References**


3.3.1.4 Irish rules

The criteria used as a basis for the warning system operated in Ireland can be summarised as follows:

(a) A 12 hour period with temperatures exceeding 10°C and relative humidity not less than 90%;

(b) Suitable conditions for free moisture to remain on the leaves for a further two hours or more;

(c) Effective blight hours (EBH's) begin on the 12th successive hour as in (a) if (to satisfy condition (b)) there is precipitation between the 7th and 15th hour. Otherwise accumulated EBH do not begin until the 16th hour;

(d) If two spells with blight conditions, the first as in (c) and the second as in (a), follow each other, within 5 hours or less between the ending of the first and the beginning of the next, no lead period of 11 or 15 hr need to be deducted for the second spell.

A period meeting these requirements is called a "blight-weather spell" and is regarded as terminated whenever even a single hour occurs at which the criteria are not met (Keane, 1982). A year of low incidence occurs when only or at most 2 spells of "blight weather" are recorded after the appearance of blight. An epidemic year is characterised by 2 or 3 blight spells close together, i.e. with less than 14 days separation, especially when the inoculum of the previous season is high. The monitor of "blight weather" in Ireland starts from mid-April until the end of September. The number of EBH is calculated and accumulated over intervals of 10 days through the season. Warnings of weather expected to be conducive to the spread of potato blight are issued as appropriate by the Meteorological Service through radio and television. They are normally issued in advance of a major blight spell so that the grower has an opportunity of spraying. Spraying only when blight warnings are issued will reduce the number of sprays.

Furthermore, for planning purposes, a simple statistical analysis of the number of EBH can be carried out (Keane, 1982). Such analysis can show the spatial distribution of the number of EBH as well as their extremes.

References


3.3.1.5 **The Norwegian rules**

Forecasting of late blight of potato in Norway was initiated in 1957. The following criteria were used:

(a) Minimum temperature >10 C for 48 h or longer;
(b) Relative humidity of > 75% at 1200;
(c) Rainfall >10 mm for the last 5 days;
(d) Mean temperature of > 14 C for the last 5 days.

In addition to a daily supply of meteorological information from the Norwegian Inst. of Meteorology, weekly information on crop development was supplied by the Agricultural Advisory service. In 1965 the warning service was reorganized using the following criteria:

(a) Maximum temperature between 17 and 24 C;
(b) Minimum temperature > 10 C
(c) Relative humidity > 75 % at 1200;
(d) Rainfall > 0.1 mm in the period.

These parameters are calculated every day for each weather station in the period from June to September and printed out in the daily weather statistics as: warning A when the parameters are calculated for 1 day, warning B for 2 consecutive days, up to warning E for 5 consecutive days or more.

References


3.3.1.6 **Poland rules**

Multiple regression equations are used for selected soil groups with adequate water (Eq. 1) or soils that are usually too dry (Eq. 2):

\[ y = -1.90 + 0.0336X_2 + 0.0040X_{14} \]  
\[ y = -5.3182 + 0.0890 X_3 \]  

where \( y = \) blight intensity; \( X_2 = \) relative humidity in June; 
\( X_3 = \) relative humidity in August, and \( X_{14} = \) total precipitation in July in mm.

The general equation which is applied to both types of soils takes the following form:

\[ y=-3.2421+0.0560X_3+0.0372X_{10} \]  

where \( X_{10} = \) number of raindays with rainfall > 0.1 mm in July.
Substituting the mean values of the meteorological parameters of the above equations a hazard index (blight intensity index) of potato blight can be estimated and therefore the mean effect of the climate on the occurrence of potato blight in a region can be evaluated. An example of such analysis is given by Utrata (1980).

References

Utrata, A., 1980. Agrometeorological conditions determining the occurrence of potato blight (Phytophthora infestans de Barry) in Poland. EPPO Bull. 10(2), 75-81.

3.3.1.7 Finland rules

The late blight warning system is based on air temperature and humidity. The daily risk rate (0-4) is calculated according to the following table:

<table>
<thead>
<tr>
<th>Average temperature when RH&gt;90%</th>
<th>Time in hours when RH&gt;90%</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.2 - 11.6</td>
<td>15 16-18 19-21 22-24 &gt; 25</td>
</tr>
<tr>
<td>11.7 - 15.0</td>
<td>12 13-15 16-18 19-21 &gt; 22</td>
</tr>
<tr>
<td>15.1 - 26.6</td>
<td>9 10-12 13-15 16-18 &gt; 19</td>
</tr>
<tr>
<td>Risk rate</td>
<td>0 1 2 3 4</td>
</tr>
</tbody>
</table>

When the risk rate of the previous 7 days is over 6 spraying is necessary during the next 5 days 5-6 " " " " " 7 days <4 no spraying is needed.

The blight sensitiveness of the variety has to be considered when making the decision to spray. In practice, most farmers are spraying as a routine against late blight even when it wouldn't be necessary.

3.3.1.8 SIMPHYT (German Democratic Republic)

The objective of this model is to describe the infection pressure at the beginning of an epidemic of potato late blight (SIMPHYT I) and to schedule the subsequent spray applications (SIMPHYT II). Precipitation in June is the decisive factor for the development of the disease. Routine spray applications are carried out every 7 to 14 days intervals. As a rule, 6 to 7 spray applications per growing season are required. However, when precipitation exceeds 10 mm a new spray application is required to be made after the crop has dried. The spray application will be interrupted when drought periods extend over a longer period of time.
References


3.3.1.9 Hyre's system (United States)

Hyre's system (Hyre, 1954) is based on records of daily rainfall and maximum and minimum temperatures. The initial appearance of late blight is predicted 7-14 days after the first occurrence of 10 consecutive blight-favourable days. A day is considered to be blight-favourable when the 5-day average temperature is below 25.5 C and the total rainfall for the last 10-day period is > 30.0 mm. Days on which the minimum temperature falls below 7.2 C are considered unfavourable for blight development.

References

3.3.1.10 **Wallin's system (United States)**

Wallin's system (Wallin, 1962) forecasts the initial occurrence and subsequent spread of late blight based on relative humidity and temperature. "Severity values" are assigned to periods of high relative humidity (Table 7 and Fig.4). Severity values increase to a maximum 4 per day with increases in the duration of high relative humidity (>90%) and with increases of temperature to 26.6 C. The initial appearance of late blight is predicted after the accumulation of 18-20 "severity values" from the time of plant emergence, and further occurrences are predicted after each subsequent accumulation of three "severity values".

Although both the Hyre and Wallin systems have been used for more than 15 years in United States, they have not been widely accepted and utilized by growers because the systems have not been readily available on a timely and regular basis.

**References**


Table 9. Relationship of temperature and relative humidity (RH) periods as used in the Wallin blight forecasting system (from Krause et al., 1975).

<table>
<thead>
<tr>
<th>Average temperature range (°C)</th>
<th>Severity Values:</th>
<th>Number of hours with RH&gt;90%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>7.2 - 11.6</td>
<td>15</td>
<td>16-18</td>
</tr>
<tr>
<td>11.7 - 15.0</td>
<td>12</td>
<td>13-15</td>
</tr>
<tr>
<td>15.1 - 26.6</td>
<td>9</td>
<td>10-12</td>
</tr>
</tbody>
</table>

* Average temperature of period when RH>90%

![Graph showing relationship between likelihood of infection and hours of RH>90% for different mean temperatures.]

Fig. 5. A suggested relationship of the duration of high relative humidity periods and the average temperature during that period to the likelihood of infection and the corresponding severity value of potato late blight (Phytophthora infestans) (after Mackenzie, 1981).
3.3.1.1

BLITECAST (United States)

1. OBJECT OF METHOD

Objective: To forecast potato late blight occurrence and schedule fungicide applications.

Title: BLITECAST

2. DESCRIPTION OF METHOD

2.1 Output (expected results and accuracy)

Blitecast produces three forms of computer output:

(a) The "long form" which is a summary of all forecasts, weather conditions, and spray recommendations made up to date for each grower.

(b) The "short form" is a five-line output which gives only the most recent forecast, weather, and spray recommendation.

(c) The "letter form" which contains all recent forecasts, spray recommendations, and messages that the blitecast operator might wish to include.

2.2 Description

Blitecast is the synthesis of the two previous systems, i.e. the Hyre system (rainfall-temperature forecasting system) and the Wallin system (relative humidity-temperature forecasting system). With both systems, the basic assumption is made that the minimal amount of late blight inoculum is always present and could develop into an epidemic under blight-favourable conditions. Blitecast has two parts:

(a) the forecast system which determines the initial occurrence of late blight 7-14 days after the accumulation of 10 consecutive blight-favourable days (Hyre system), or 18-20 "severity values" (Wallin system); and

(b) the scheduling of subsequent applications system which recommends spray applications based on the number of rain-favourable days and "severity values" accumulated during the previous 7-day period (Table 10). The first spray application is recommended when the first late blight forecast is given. A late blight warning indicates marginal blight weather and the grower is advised that he should either spray or submit additional data in 2 or 3 days for another Blitecast. If a grower receives a late blight warning and the short range forecast is for "blight favourable" weather, the spray recommendation is changed to a 7-day spray schedule. A 5-day spray schedule occurs only during severe blight weather.
 Modifications were attempted by Fry et al., (1983) to incorporate in Blitecast some of the effects of plant resistance to estimate the frequency of fungicide applications to various resistant varieties. They developed the concept of "blight units" which are determined by cultivar resistance, temperature and periods of high relative humidity (>90%) (Table 11) as well as the concept of "fungicide units" which are determined by rainfall and time since last fungicide application (Table 12). The need for an additional fungicide spray is indicated by the accumulation of a minimum number of "blight units" or a minimum number of fungicide units (Table 13).
2.3 Input data

(a) Meteorological data:

1. Maximum and minimum temperatures.
2. Number of hours with relative humidity > 90%
3. Daily rainfall

(b) Crop data: Data must be recorded from "greenrow" stage (the date when distinct green rows can be seen in the field) until complete vine kill. The resistance of the variety to potato late blight.

2.4 Operational requirements (including computer requirements)

Micro-or mini computer

Validity limits imposed by basic concept, constraints in application.

1. Experimental results in United States showed that when the Blitestation was not located within the crop canopy, Blitecast accurately predicted the occurrence of late blight but was not successful in the timing of spray recommendations (Krause et al., 1975).

2. Comparing the performance of Blitecast and the application of fungicide at regular time intervals it was found that for microclimates favourable for late blight the use of Blitecast resulted in a higher average number of fungicide applications than did application at 7-day intervals. With low exposure to inoculum, both schemes resulted in very low average defoliation (Table 14). With high or moderate exposure to inoculum, routine applications at 7-day intervals resulted in less average defoliation than did applications made according to Blitecast.

For moderately favourable microclimates the use of Blitecast resulted in an average 1.3 fewer applications of fungicide than the 7-day interval. However, when exposure to inoculum was moderate or high, the potential value of using Blitecast was further diminished because the disease was higher than with the routine 7-day application (Table 11).

In unfavourable microclimates, Blitecast resulted in an average 3.4 fewer fungicide applications than the weekly applications. However, for moderate and high exposure to inoculum the reductions in fungicide use were associated with an increase in average defoliation with virtually no increase in average disease (Table 14) (Fohner et al., 1984).

3. The suggested modifications by Fry et al. (1983) underestimated host resistance effects and caused more than the necessary number of fungicide applications.
4. Nutter and MacHardy (1980) attempted to eliminate some criteria from Blitecast matrix without loosing its readability. They came into conclusion that the following criteria can be neglected: (a) a minimum temperature < 7 C; (b) a 5-day average temperature >26 C is blight-unfavourable day; and (c) a maximum temperature > 30 C cancels the previous day's severity value.

5. Weather map interpretation and projection could greatly enhance the system. Severity values could be estimated in advance and growers would be able to plan fungicide spray schedules.

References


Table 10. Adjustable matrix used to relate "severity values" (Wallin's system) and rain-favourable days (Hyre's system) and generate spray recommendations for Blitecast (from Krause et al., 1975).

"Severity values" during last seven days
<3  3  4  5  6  >6
Message Number

Total rain-favourable  <5  -1  -1  0  1  1  2
Day during last seven days  >4  -1  0  1  2  2  2

<table>
<thead>
<tr>
<th>Message Number</th>
<th>Spray Recommendations</th>
</tr>
</thead>
<tbody>
<tr>
<td>-1</td>
<td>No spray</td>
</tr>
<tr>
<td>0</td>
<td>Last blight warning</td>
</tr>
<tr>
<td>1</td>
<td>Seven-day spray schedule</td>
</tr>
<tr>
<td>2</td>
<td>Five-day spray schedule</td>
</tr>
</tbody>
</table>

Table 11. Blight units as determined by cultivar resistance, temperature and periods of high relative humidity (% 90%).

<table>
<thead>
<tr>
<th>Temperature ('C)</th>
<th>Cultivar Resistance</th>
<th>Hours of Relative Humidity ≥ 90 %</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;21</td>
<td>Suscept.</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>Mod suscept.</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>Mod resist.</td>
<td>24</td>
</tr>
<tr>
<td>23-27</td>
<td>Suscept.</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Mod suscept.</td>
<td>7-9</td>
</tr>
<tr>
<td></td>
<td>Mod resist.</td>
<td>10-18</td>
</tr>
<tr>
<td></td>
<td></td>
<td>19-24</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>23-27</td>
<td>Suscept.</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Mod suscept.</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Mod resist.</td>
<td>8-9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10-12</td>
</tr>
<tr>
<td></td>
<td></td>
<td>13-15</td>
</tr>
<tr>
<td></td>
<td></td>
<td>16-18</td>
</tr>
<tr>
<td></td>
<td></td>
<td>19-24</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13-22</td>
<td>Suscept.</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Mod suscept.</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Mod resist.</td>
<td>8-9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10-12</td>
</tr>
<tr>
<td></td>
<td></td>
<td>13-15</td>
</tr>
<tr>
<td></td>
<td></td>
<td>16-18</td>
</tr>
<tr>
<td></td>
<td></td>
<td>19-24</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9-12</td>
<td>Suscept.</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Mod suscept.</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Mod resist.</td>
<td>8-9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10-12</td>
</tr>
<tr>
<td></td>
<td></td>
<td>13-15</td>
</tr>
<tr>
<td></td>
<td></td>
<td>16-18</td>
</tr>
<tr>
<td></td>
<td></td>
<td>19-24</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3-7</td>
<td>Suscept.</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Mod suscept.</td>
<td>7-9</td>
</tr>
<tr>
<td></td>
<td>Mod resist.</td>
<td>10-12</td>
</tr>
<tr>
<td></td>
<td></td>
<td>13-15</td>
</tr>
<tr>
<td></td>
<td></td>
<td>16-18</td>
</tr>
<tr>
<td></td>
<td></td>
<td>19-24</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3-7</td>
<td>Suscept.</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Mod suscept.</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Mod resist.</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>Suscept.</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>Mod suscept.</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>Mod resist.</td>
<td>24</td>
</tr>
</tbody>
</table>

Blight units:
0  1  2  3  4  5  6  7

* From Fry et al., 1983.*

Key: Suscept. = susceptible; Mod. = moderately; Resist. = resistant.

* Blight units are given for each column.
Table 12. Fungicide units for chlorothalonil as determined by rainfall and time since last fungicide application.

<table>
<thead>
<tr>
<th>Days since Fungicide Application</th>
<th>Daily Rainfall (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>&lt;1</td>
</tr>
<tr>
<td>2</td>
<td>&lt;1</td>
</tr>
<tr>
<td>3</td>
<td>&lt;1</td>
</tr>
<tr>
<td>4-5</td>
<td>&lt;1</td>
</tr>
<tr>
<td>6-9</td>
<td>&lt;1</td>
</tr>
<tr>
<td>10-14</td>
<td>&lt;1</td>
</tr>
<tr>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>

Fungicide units:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |

*From Fry et al. (1983).

Table 13. Decision rules for the cumulative fungicide units for potato late blight.

<table>
<thead>
<tr>
<th>Cultivar Resistance</th>
<th>Susceptible</th>
<th>Moderately Resistant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fungicide should be applied if fungicide has not been applied within 5 days</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AND cumulative fungicide units since last spray exceed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>OR cumulative fungicide units since last spray exceed</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*From Fry et al. (1983)

Table 14. Average defoliation from late blight and average number of fungicide applications for 10 replicated seasons for spraying according to BLITECAST and at 7-day intervals.

<table>
<thead>
<tr>
<th>Microclimate</th>
<th>Favourable</th>
<th>Moderately Favourable</th>
<th>Unfavourable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Number of Fungicide Applications per Season</td>
<td>BLITECAST</td>
<td>7-day</td>
<td>BLITECAST</td>
</tr>
<tr>
<td>10.6</td>
<td>10</td>
<td>8.7</td>
<td>10</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Exposure to inoculum</th>
<th>Average Percent Defoliation</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>40.1 (7.9)</td>
</tr>
<tr>
<td>Moderate</td>
<td>16.3 (6.0)</td>
</tr>
<tr>
<td>Low</td>
<td>0.2 (0.1)</td>
</tr>
</tbody>
</table>

*Data are from Pohner et al. (1984).

*Values in parentheses are standard deviation of average defoliation.
3.3.2 Negative forecasting systems

3.3.2.1 PHYTPROG (Federal Republic of Germany, Switzerland, Austria, Denmark, Yugoslavia)

1. OBJECT OF METHOD

1.1 Objective:

1. To calculate the minimum period when an epidemic propagation of the disease will be reached. So, the procedure does not yield any prognosis of the event "epidemic outbreak of the disease", but only a forecast of the earliest possible date the event may occur (negative prognosis).

2. To detect areas especially susceptible to the disease from the frequency distribution for both the weekly and total Phytophthora indices (WPI and TPI).

Title: PHYTPROG

2. DESCRIPTION OF METHOD

2.1 Output (expected results and accuracy)

Weekly and Total Phytophthora indices (WPI and TPI). An extrapolation of the TPI allows to estimate the time when TPI will reach the threshold values of 150 or 270. Then the results are made available to Plant Protection Services through the weekly Bulletin "Agrarmeteorologische Vochenhinweis", as well as via view data. Then the Plant Protection Services prepare for the farmers recommendations which are publicized via view data or made available by post and phone.

2.2 Description

The model was developed by Schroeder and Ullrich (1965, 1966, 1967). It describes the interaction of the meteorological elements of air temperature (T), relative humidity (RH) and precipitation (P) on the propagation of the disease. The hourly observations of these elements are required to compute the Weekly Phytophthora Index (WPI) which is given by the equation:

\[ WPI = \sum_{k=1}^{m} \Delta h_k.f(x_k) \quad m = 1, 4 \quad (1) \]

where \( h_k \) are the frequencies of temperatures in each temperature class \( k \) and \( f(x_k) \) are the relevant constants (Table 15). Then the Total Phytophthora Index (TPI) is computed by the accumulation of the weekly indices (WPI) starting from the time of crop emergence. An infection of 0.1% is defined as the value for the beginning of an epidemic disease; this corresponds to TPI = 150 (first critical date). In case of an infection of 1% or TPI = 270 (second critical date), the threshold for control of the fungus is exceeded as required from the economic point of view.
2.3 Input data
(a) Meteorological data: Hourly values of temperature, relative humidity and precipitation.
(b) Crop data: Date of crop emergence.

2.4 Operational requirements (including computer requirements)
Programmable calculator or micro-computer.

2.5 Validity, limits imposed by basic concept, constraints in application:

1. The model uses purely statistical methods.

2. Experimental results in the Federal Republic of Germany showed that the disease can not appear before TPI reach the value of 150. It was also shown that the disease can be expected in most cases when TPI=270 (Schiessndoppler, 1980; Schiff and Schröder, 1984).

3. Using micrometeorological measurements the output was not improved when comparing with data collected from the screen (Schiff and Schröder, 1984).

4. The method can be also used in warmer climates, when the time of irrigation and the amount of water applied to the crop are known in order to estimate the WPI.

3. VALIDATION/PROVEN USES

The model is in operational use in four countries i.e. Federal Republic of Germany, Switzerland, Austria and Denmark. The warning system of Denmark is based on a combination of the van Everdingen’s rules and the "negative forecasting system". The method was also applied in Yugoslavia.

References


Table 15. Table obtained from Ullrich and Schrodter (1966) showing the calculation of the Weekly Phytophthora Index (WPI). (1 week = 168 hours).

<table>
<thead>
<tr>
<th>Propagation of fungus</th>
<th>Multiplication factor ([f(X))]</th>
<th>Temperature class intervals used to estimate the frequencies ([h_x]) of the hourly values of temperature ((T)) in one week</th>
<th>Effects of relative humidity ((RH)) and precipitation ((P))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Germination of spores &amp; infection</td>
<td>0.8990</td>
<td>10.0-11.9</td>
<td>The frequency of those hourly values of (T) is only encountered for humid periods of at least 4 hours with (RH&gt;90%) or (P&gt;0.1) mm/hr</td>
</tr>
<tr>
<td></td>
<td>0.4118</td>
<td>14.0-15.9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.5336</td>
<td>16.0-17.9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.8816</td>
<td>18.0-19.9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.0498</td>
<td>20.0-21.9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.5858</td>
<td>22.0-23.9</td>
<td></td>
</tr>
<tr>
<td>Production of sporangia</td>
<td>0.3924</td>
<td>10.0-11.9</td>
<td>The frequency of those hourly values of (T) is only encountered for humid periods of at least 10 hours with (RH&gt;90%) or (P&gt;0.1) mm/hr</td>
</tr>
<tr>
<td></td>
<td>0.0702</td>
<td>14.0-15.9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.1278</td>
<td>16.0-17.9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.9108</td>
<td>18.0-19.9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.4706</td>
<td>20.0-21.9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.8550</td>
<td>22.0-23.9</td>
<td></td>
</tr>
<tr>
<td>Growth of mycelium</td>
<td>0.1639</td>
<td>15.0-19.9</td>
<td>This is not influenced by (RH) or (P). The maximum value of (h_x f(X)) = 7.6479</td>
</tr>
<tr>
<td>Unfavourable constellations</td>
<td>0.0468</td>
<td>independent of temperature</td>
<td>Frequencies of (RH&lt;70%). The maximum value which can be reached is (h_x f(X)) = 7.8624</td>
</tr>
</tbody>
</table>
3.3.2.2 Negative forecasting system in Israel

1. OBJECT OF METHOD

1.1 Objective: To estimate the disease-free period for Phytophthora infestans on irrigated potatoes in order to avoid unnecessary spraying.

Title: Negative forecasting system

2. DESCRIPTION OF METHOD

2.1 Output (expected results and accuracy)

Estimation of the disease-free period from temperature measurements.

2.2 Description

The disease-free period (y) is linearly related to the mean daily temperature [(Tmax+Tmin)/2] during the first 30 days after planting (Fig. 6). It appears from the figure that when the mean daily temperature during the first 30 days after planting is low (10-12°C), the disease-free period will extend to 60-70 days. Within the temperature range of 14-17°C, no relationship was found, although a disease-free period of 40-45 days can be expected. Finally, when the mean daily temperature ranges between 17 and 20°C, the disease-free period varies between 60 and 70 days.

2.3 Input data

Meteorological data: Daily maximum and minimum temperatures

Crop data: Time of planting

2.4 Operational requirements (including computer requirements)

Programmable calculator

2.5 Validity, limits imposed by basic concept, constraints in application.

The relationship is empirical. Therefore, different regression equations will be obtained from coastal and inland areas. The sensitivity of the cultivar is not taken into account. Different relationships must be established for early or late potato cultivars.

3. VALIDATION/PROVEN USES

The method is in operational use in Israel with good results.
4. References


Fig. 5. Relationship between temperature during the first month after planting and the age of the potato crop at blight appearance. Spring planting - coastal plain, and northern Negev. $y =$ age of days after planting at which the disease appeared and $x$ the mean daily temperature for the first 30 days after planting.
3.3.3 SIMULATION MODELS

3.3.3.1 BLIGHT (England)

1. OBJECT OF METHOD

1.1 Objective:

To relate the progress of potato blight and its environment in a way that it will allow the development of the disease to be calculated through the season.

To identify synoptic situations that promote blight and to evaluate various control strategies.

To study past blight epidemics.

2. DESCRIPTION OF METHOD

2.1 Output (expected results and accuracy)

At the end of each day, the model calculates the number of sporulating lesions, the number of spores they produce, the number of resulting new infections and finally a running total of the number of lesions produced since the start of the season, together with the corresponding percentage of the haulm destroyed. The possible magnitude of new infections each day is given by the parameter INFECT which takes the values 0(nil), 1(light), 2(moderate) or 3(heavy).

Information on the parameter INFECT for about 100 weather stations in the U.K. was calculated and distributed to plant pathologists. The information, together with field reports was used by the pathologists to build up a picture of the disease situation in a given region. Disease reports were issued weekly and contain summaries of the disease situation and advice on treatment.

2.2 Description

The stages in the development of the disease that are explicitly modelled by BLIGHT are: growth of spores, survival of spores, incubation of infections, and senescence of lesions. Some important processes, such as detachment and spread of spores, their deposition, germination and infection on host leaves are not explicitly modelled but they are simply assumed to happen. The model also assumes that there is always at least one lesion that is capable of sporulating, given the right weather conditions.

A simplified version of the model is described in Table 16. Spore growth is related to temperature and duration of humid period. Spore growth is classed as nil, light, medium and heavy and is denoted by values of a parameter SP as 0, 1, 2, 3 respectively.
Humidity is considered as the most important factor for spore survival (ss). This parameter takes values from 0 (low survival) to 3 (high survival) depending on whether the duration of dew point depression is equal or more than 4°C (a relative humidity > 80%) for 9 to 12 hours, 5 to 8 hours, 2 to 4 hours or 0 to 1 hour respectively. It is assumed that any humid period as defined in Table 16 would be sufficient for germination and infection, this process is characterised by the parameter GI which takes the value 1 if there is a humid period between 1800 and 0900; otherwise it is zero.

Finally the model estimates the magnitude of new infection each day which is defined by the parameter INFECT which is related to the previously mentioned parameters (Table 16). INFECT varies from 0 to 3 corresponding to nil, light, moderate or heavy infection. The calculation of blight infections for day "DAY" is made after 0900 GMT on DAY+1. The values of SP, SS and GI depend on weather observations at particular times of the day as shown in Fig. 7. A flow diagram showing the procedure for the calculation of INFECT is shown in Fig. 8.

2.3 Input data

Meteorological data: Hourly values of temperature, dew point, precipitation and observation on fog.

Crop data: Information about the phenological stages of the crop, i.e. (i) plants easily distinguishable from a distance as individuals; (ii) foliage meeting in but not across rows, stems erect (iii) foliage meeting both in and across rows and forming a complete canopy; and (vi) prostrate stems with erect side branches.

2.4 Operational requirements (including computer requirements)

Micro or mainframe computer

2.5 Validity limits, imposed by basic concept, constraints in application:

1. Using the model for various parts of England the majority of predicted dates of the appearance of the disease were within ±10 days of the observed dates. Predictions were more accurate than Smith or Beaumont periods.

2. The model calculates the blight progress in a standard main crop from a source of infection within the crop. It can not be used to calculate the development of blight on dumps and earlies.
3. VALIDATION/PROVEN USES

Based on the evidence of past seasons, it was shown that in order to obtain the best possible warning system it is necessary to maintain the two systems running together with the emphasis on Smith periods early in the season and on Blight estimations later in the season.

4. REFERENCES


Table 16

DEFINITIONS

HUMID PERIOD

A humid period starts or continues when:

There is rain, hail, snow, drizzle or fog at the time of the observations or during the past hour.

OR The dew point depression in the crop is less than or equal to 1.6°C.

The humid period ends when none of the above are satisfied and only those hours at which the above conditions are satisfied are counted as part of the humid period if the hour on which it ends is not counted.

DURATION

D is the length of the humid period in hours.

TEMPERATURE

$\bar{T}$ is the average temperature during the humid period ($^\circ$C).

SPORO PRODUCTION

SP is calculated from D and $\bar{T}$ using the following rules.

\[
\begin{align*}
\text{IF } \bar{T} < 3 & \text{ THEN } D_1 = 999, \quad \text{IF } \bar{T} > 18 & \text{ THEN } D_1 = 8 \quad \text{ELSE } D_1 = 1/(0.00787\times \bar{T} - 0.0167) \\
\text{IF } \bar{T} < 5 & \text{ THEN } D_2 = 999, \quad \text{IF } \bar{T} > 18 & \text{ THEN } D_2 = 11 \quad \text{ELSE } D_2 = 1/(0.006734\times \bar{T} - 0.030303) \\
\text{IF } \bar{T} < 6 & \text{ THEN } D_3 = 999, \quad \text{IF } \bar{T} > 18 & \text{ THEN } D_3 = 14 \quad \text{ELSE } D_3 = 1/(0.00562\times \bar{T} - 0.0298) \\
\text{IF } D > D_3 & \text{ THEN } SP = 3 \\
\text{IF } D_3 > D > D_2 & \text{ THEN } SP = 2 \\
\text{IF } D_2 > D > D_1 & \text{ THEN } SP = 1 \\
\text{IF } D < D_1 & \text{ THEN } SP = 0
\end{align*}
\]

SPORO SURVIVAL

SS is calculated using the number of hours from 0600 to 1700 GMT inclusive with dewpoint depression in the crop more than 4°C (SDPD).

\[
\begin{align*}
9 \text{ to } 12 \text{ hours with dewpoint depression more than } 4^\circ \text{C} & \quad SS = 0 \\
5 \text{ to } 8 \text{ " } & \quad SS = 1 \\
2 \text{ to } 4 \text{ " } & \quad SS = 2 \\
0 \text{ or } 1 \text{ " } & \quad SS = 3
\end{align*}
\]

GERMINATION AND INFECTION

GI = 1 if there is a humid period between 1800 and 0900 GMT, otherwise GI = 0.
INFECT is the estimated magnitude of the spread of new infections and is obtained from the values of \( SP \) and \( SS \) according to the table below when \( GI = 1 \) but is reduced by 1 category when \( GI = 0 \).

\[
\begin{array}{cccc}
\text{SP} & 0 & 1 & 2 & 3 \\
\text{SS} & & & & \\
0 & 0 & 0 & 0 & 0 \\
1 & 0 & 0 & 0 & 1 \\
2 & 0 & 0 & 1 & 2 \\
3 & 0 & 1 & 2 & 3 \\
\end{array}
\]
PERIODS FOR CALCULATION OF BLIGHT INFECTIONS

Day - 1  |  Day  |  Day +1

Hour  |  18   |  00   |  06   |  17   |  18   |  00   |  09

* Period for SP Calculation
   Period for SS Calculation
   Period for GI Calculation

SP = Spore Production
SS = Spore Survival
GI = Germination and Infection

* Information about any humid period already in progress at 18 hours on DAY - 1 is brought forward into the calculation of SP.
FLOW CHART FOR CALCULATION OF INFECTION

**KEY**
- DPD = dew point depression
- D1 = minimum duration of a humid period with temp T for light sporulation
- GI = index of germination and infection
- H = hour of day
- EH = number of hours in a humid period
- SDPD = number of hours with DPD > 4°C
- SP = index of spore production
- SP = sum of spore production indices
- SS = index of spore survival
- T = hourly temperature
- ET = sum of hourly temperatures in a humid period
- T = mean temperature during a humid period

---

START

GET EH, ET FROM PREVIOUS DAY
SET SDPD = 0

GET DATA FOR NEXT HOUR

DAY-1?

YES

EH = EH + 1
ET = ET + T
HUMID?

NO

EH > 0

CALCULATE SP
SP = SP + SP

2H = ET + SP = 0

NO

YES

DAY?

NO

H < 17

NO

YES

GI = 1

H = 09

YES

HUMID?

NO

YES

HUMID?

NO

YES

CALCULATE SS

SS FROM SDPD

STORE EH AND ET FOR NEXT DAY

END
3.3.3.2 A simulation model of Phytophthora infestans (Cyprus)

1. OBJECT OF METHOD

1.1 Objective: To develop a simulation model using published information on the biology of the fungus, and estimate the progress of the disease as it is affected by the prevailing weather conditions.

2. DESCRIPTION OF METHOD

2.1 Output (expected results and accuracy): An estimate of the cumulative totals of infections and lesions.

2.2 Description

The model operates on a three hourly time step and simulates the effect on spore production which gives an estimate of the progress of the epidemic in terms of the number of new infections and lesion formed at the end of each day, as well as the cumulative totals of infections and lesions (Fig. 9). A sensitivity analysis was performed to test the effect of rainfall intensity, wind and age of lesions on the progress of the disease.

2.3 Input data

Meteorological data: Dry and wet temperature, wind speed and rainfall at 3 hours intervals.

Crop data: Number of plants per km$^2$ and leaf area index.

2.4 Operational requirements (including computer requirements)

Microcomputer.

2.5 Validity, limits imposed by basic concept, constraints in application:

1. The model simplifies some processes due to lack of information.

2. The complex interaction between the potato plants and the fungus is not considered in detail.

3. VALIDATION/PROVEN USES

Validation using actual phytopathological and meteorological data is essential before the model can be used operationally.

The performance of the model can be improved by adding new components whenever this appears to be necessary.
4. REFERENCES


Contacts

S.C. Michaelides
Meteorological Service
Nicosia
Cyprus
Fig. 9. Life cycle of the fungus as it is represented in the model.
References


Table 17. Factors influencing the development of Phytophthora infestans and operation of the model to simulate potato blight epidemics (From Bruhn and Fry, 1981).

<table>
<thead>
<tr>
<th>Stage of pathogen development</th>
<th>Factors affecting process</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spore production</td>
<td>Temperature, relative humidity, cultivar</td>
</tr>
<tr>
<td>Dispersal</td>
<td>Leaf wetness, rainfall, proportion of susceptible tissue</td>
</tr>
<tr>
<td>Germination</td>
<td>Temperature, leaf wetness</td>
</tr>
<tr>
<td>Infection</td>
<td>Temperature, leaf wetness, cultivar, fungicide</td>
</tr>
<tr>
<td>Lesion expansion</td>
<td>Temperature, cultivar, proportion of susceptible tissue</td>
</tr>
</tbody>
</table>
3.3.3.4 Potato Disease Management (PDM) (United States)

1.1 OBJECT OF METHOD

1.1 Objective: To provide information and warning to potato growers of the potential for the development of early and late blight diseases and to schedule fungicide applications for disease prevention and control.

2. DESCRIPTION OF METHOD

2.1 Output (expected results and accuracy)

Determination of the expected date of late blight disease occurrence when inoculum is present and when an increase in airborne spores of the early blight fungus is most likely.

Recommended spray intervals are adjusted for control of both diseases on the basis of weather conditions.

Recommended rates of fungicide use for control of early blight disease are adjusted for environmental conditions and differences in susceptibility to early blight between potato cultivars.

2.2 Description

Potato Disease Management (PDM) is comprised of two major components. The first component focuses on early blight management and is based on the calculation and accumulation of 300 physiological days (P-Days) from daily maximum and minimum temperatures. The model uses leaf wetness, air temperature, relative humidity and rainfall to calculate daily severity and rating values that quantitatively represent conditions favorable for early blight development. A total of 35 severity values accumulated a few days before a large increase in the concentration of airborne spores are used to determine the initial fungicide applications. Subsequent scheduling is based on the accumulation of 300 P-Days. The second component focuses on the management of potato late blight and is based on the BLITECAST computer program developed at the Pennsylvania State University.

2.3 Input data

Meteorological data: Hourly values of air temperature and relative humidity, leaf wetness records and daily rainfall totals.

Crop data: Green-row stage

2.4 Operational requirements (including computer requirements)

Microcomputers
2.5 Validity, limits imposed by basic concept, constraints in application. The PDM program can be considered as a management tool that can assist growers in controlling early and late blight diseases of potato.

3. VALIDATION/PROVEN USES

The model has been applied successfully in Wisconsin.

4. References


5. CONTACTS

W.R. Stevenson, UW Extension Plant Pathologist and Professor of Plant Pathology, Department of Plant Pathology, 283 Russell Laboratory, University of Wisconsin, 1630 Linden Drive, Madison, WI 53706.
3.3.4 Warning Systems for other pests and diseases

3.3.4.1 Warning Systems for potato early blight (Alternaria Solani)

(a) Growing degree-days (GDD) method (United States)

Weekly sprays are initiated when 1000 GDD above 7°C have been accumulated from emergence. On average 3 fewer fungicide applications than the conventional schedule can be used.

(b) Physiological days (P-Days) method (United States)

Weekly sprays are initiated when 300 P-Days (physiological days) have been accumulated from emergence. The accumulation of P-Days for a 24-hr period, based on maximum and minimum temperatures is calculated from the following equations:

\[
P\text{-Days} = (1/24)\left[5P(T_{\text{min}})+8P(T_{\text{min}}/3+T_{\text{max}}/3)+8P(2T_{\text{max}}/3+T_{\text{min}}/3 +
3P(T_{\text{max}}))\right]
\]

if \(T < 7\)°C then \(P(T) = 0\)

if \(7 < T < 21\)°C then \(P(T)=10[1-(T-21)^2/(21-7)^2]\)

if \(21 < T < 30\)°C then \(P(T)=10[1-(T-21)^2/(30-21)^2]\)

if \(30 < T\) then \(P(T) = 0\)

\(T =\) hourly temperature (°C) from thermohygrograph

\(T_{\text{max}} =\) daily maximum temperature (°C)

\(T_{\text{min}} =\) daily minimum temperature (°C)

Spray schedules based on P-Day accumulation were able to control effectively early blight using an average of two sprays fewer than the conventional schedule, i.e. spraying when plants are 20-25 cm tall.

(c) FAST model (United States)

This model determines both the initial spray against Alternaria Solani as well as the time interval of the subsequent sprays. Initial spray is applied after 35 severity values (based on leaf wetness and temperature) have been accumulated from emergence. Subsequent sprays are applied at 7-day intervals when >11 severity values have been accumulated in the last 7 days, or at 5-day intervals when >11 severity values have been accumulated in the last 7 days and >8 rating values (based on temperature, humidity and rainfall) have been accumulated in the last 5 days (Tables 18 and 19).

Generally FAST model recommends about 2 fewer fungicide sprays than conventional programme.
References


TABLE 18. Relationship of leaf wetness period and average temperature during the wetness period to severity values using model one.

<table>
<thead>
<tr>
<th>Mean T°C</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hours, Leaf Wetness</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13-17 C</td>
<td>0-6</td>
<td>7-15</td>
<td>16-20</td>
<td>21+</td>
<td></td>
</tr>
<tr>
<td>18-20 C</td>
<td>0-3</td>
<td>4-8</td>
<td>9-15</td>
<td>16-22</td>
<td>23+</td>
</tr>
<tr>
<td>21-25 C</td>
<td>0-2</td>
<td>3-5</td>
<td>6-12</td>
<td>13-20</td>
<td>21+</td>
</tr>
<tr>
<td>26-29 C</td>
<td>0-3</td>
<td>4-8</td>
<td>9-15</td>
<td>16-22</td>
<td>23+</td>
</tr>
</tbody>
</table>

*Average temperature during wetness period.*

TABLE 19. Relationship of average temperature for the past 5 days, hours of relative humidity greater than 90% for the past 5 days and total rainfall for the past 7 days to severity rating values using model two.

<table>
<thead>
<tr>
<th>Temperature Average 5 Days</th>
<th>Hours RH&gt;90 5 Days</th>
<th>Total Rain 7 Days</th>
<th>RATING</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;22 C</td>
<td>&lt;60</td>
<td>&lt;1.0 inch</td>
<td>0</td>
</tr>
<tr>
<td>&gt;22</td>
<td>&lt;60</td>
<td>&lt;1.0</td>
<td>0</td>
</tr>
<tr>
<td>&lt;22</td>
<td>&gt;60</td>
<td>&lt;1.0</td>
<td>1</td>
</tr>
<tr>
<td>&lt;22</td>
<td>&lt;60</td>
<td>&gt;1.0</td>
<td>1</td>
</tr>
<tr>
<td>&lt;22</td>
<td>&gt;60</td>
<td>&gt;1.0</td>
<td>1</td>
</tr>
<tr>
<td>&gt;22</td>
<td>&gt;60</td>
<td>&lt;1.0</td>
<td>2</td>
</tr>
<tr>
<td>&gt;22</td>
<td>&lt;60</td>
<td>&gt;1.0</td>
<td>2</td>
</tr>
<tr>
<td>&gt;22</td>
<td>&gt;60</td>
<td>&gt;1.0</td>
<td>3</td>
</tr>
</tbody>
</table>
3.3.4.2 **Nematode potato model** (The Netherlands)

1. **OBJECT OF METHOD**

1.1 **Objective:** To simulate the population dynamics of the potato cyst-nematode, *Globodera pallida* and its effect on the growth of the potato.

2. **DESCRIPTION OF METHOD**

2.1 **Output (expected results and accuracy)**

Number of population of potato cyst-nematode and estimation of yield losses.

2.2 **Description**

The model combines two sub-models: a potato growth model and a nematode population model. The potato growth model is based on the summary growth model SUCROS which simulates the dry matter growth of leaves, roots and tubers, as a function of temperature and irradiation. The second sub-model simulates the changing numbers of individual nematodes in each of seven development classes: mature eggs, eggs stimulated to hatch, free larvae, parasitic 2nd stage larvae, 3rd and 4th stage larvae, adult females and eggs in dormant cysts. The structure of the model is represented in a relational diagram in Fig. 10.

2.3 **Input data**

Meteorological data: Daily maximum and minimum temperatures as well as soil temperatures at 30 cm depth and solar radiation

Crop data: Dates of various crop phenological stages and parasitic stages

2.4 **Operational requirements (including computer requirements)**

Micro or mini computer

2.5 **Validity, limits imposed by basic concept, constraints in application.**

1. Despite its simplicity the model has shown good agreement with several features of the real system, i.e. the relation between initial and final density of eggs in the soil, the effect of harvest date, the effect of initial egg density on the yield of tubers and the changes of nematode density during the potato growing season.

2. Several other characteristics can be incorporated into the model, i.e. cultivar differences in hatching stimulus, resistance or tolerance due to root vigour, water balance, and the effect of nematode invasion on the various crop developmental stages of the crop.
3. VALIDATION/PROVEN USES

The model is in operational use by a number of farmers in the Netherlands.

4. References


Fig 10: Relational diagram of growth and development of the potato plant and the cyst-nematode, Globodera pallida.
Rectangles: state variables; Valve symbols: rate variables; Underlined: driving variables.
- - Flow of material; ---- Flow of information.
3.3.4.3 Forecasting of the incidence of potato aphids in Scotland

Degree-days, derived from the daily maximum and minimum temperatures above or below 5°C are estimated during the period from November to April when aphid flight hardly occurs. The threshold of 5°C is approximated to the developmental threshold of many aphid species. The daily values above and below 5°C are calculated and summed for each month, and all consecutive combinations, from November to April. The values are then expressed as the differences between degrees above and below 5°C. According to established regression equations between the aphid arrival date and the difference in accumulated degree-days above and below 5°C the date of incidence of potato aphids can be predicted.

With seed potatoes, control of aphid-borne viruses is the main concern and relative earliness of aphid colonization is particularly important in respect to the extend of virus spread.

References

3.4 Spraying forecasts

Studies concerning the factors which determined the spray drift are of considerable importance. Several criteria can be used to identify occasions suitable for spraying according to the chemical used. This section provides information about the models which can be used to estimate the drift deposit densities downwind of sprayed areas and the criteria for spraying conditions as used in United Kingdom.

3.4.1 A simple model of spray drift

1. OBJECT OF METHOD

1.1 Objective:

1. To estimate numbers of drops likely to become airborne initially.

2. To calculate the consequent pattern of deposit densities downwind of the sprayed area.

3. To provide a useful guidance on the interrelations between drift and weather.

2. DESCRIPTION OF METHOD

2.1 Output (expected results and accuracy)

Estimation of drip deposits densities downwind of sprayed areas.

2.2 Description

The main components of weather which influence drift are wind (speed and direction), atmospheric stability and temperature and humidity. Wind speed controls the number and size of the spectrum of drops which become "airborne" (to form drift). Atmospheric stability has a considerable influence on the time the smaller drops remain airborne. Temperature and humidity influence the rate at which the drops evaporate, and hence to some extent the time they remain airborne. The atmospheric stability is classified according to the scheme developed by Pasquill (1961). The variables which are estimated in the model are: the final size of drop, the "stopping distance", the effective release height of the drift, and the drift deposit densities downwind of sprayed areas.
2.3 Input data

Meteorological data: Wind speed at 10 m, Solar radiation and cloudiness, temperature and humidity.

Management data: Ejection speed of the spraying system.

2.4 Operational requirements (including computer requirements)

Micro-computer

2.5 Validity, limits imposed by basic concept, constraints in application

Estimates of drift deposit densities appear to be in broad agreement with the available experimental results. Drop evaporation is not considered in the model, and therefore the approach is not suited to those cases in which the effects of drop evaporation are important.

3. VALIDITY/PROVEN USES

The model provides an approach to quantify the effects of meteorological factors on spray drift.

4. REFERENCES


3.4.2 Random-walk model

1. OBJECT OF METHOD

1.1 Objective: To determine the drift deposits by simulating the trajectories of a large number of individual drops.

2. DESCRIPTION OF METHOD

2.1 Output (expected results and accuracy)

Surface deposits downwind of sprayed areas.

2.2 Description

The model is based on the Markov-Chain in which the velocity at any time step is related to the velocity of the previous time step with the addition of a random component and the fall speed of the drop. The variables used in the model are the drop size, wind speed, atmospheric stability, rate of evaporation, height of release, and the efficiency of collection of drops by the underlying surface.

2.3 Input data

Meteorological data: Wind speed at 10 m, solar radiation, cloudiness, temperature and relative humidity.

Crop data: Crop height

Management data: Effective release height above crop Initial drop sizes.

2.4 Operational requirements (including computer requirements)

Micro-computer

2.5 Validity, limits imposed by basic concept, constraints in application.

Although the random-walk model can produce satisfactory results in well-defined conditions, much empiricism has been used which limits its application to more general problems. Extrapolation of the results in not recommended.
3. VALIDITY/PROVEN USES

The model is a valuable aid in quantifying spray drift.

4. REFERENCES


3.4.3 **Spray-occasion criteria**

1. **OBJECT OF METHOD**

1.1 Objective:

1. To identify occasions likely to be suitable for spraying herbicides with different types of chemicals.

2. To compare places and seasons.

2. **DESCRIPTION OF METHOD**

2.1 Output (expected results and accuracy)

Seasonal summaries of spraying hours

2.2 Description

The criteria used to identify occasions suitable for spraying using four different types of chemicals are given in Table 20.

2.3 Input data

Meteorological data: Hourly data of temperature, visibility, wind speed, rainfall and relative humidity.

2.4 Operational requirements (including computer requirements)

Micro-computer

2.5 Validity, limits imposed by basic concept, constraints in application

There are small differences between the number of spray-occasions with "contact", "contact-hormone" and "hormone" criteria.

3. **VALIDITY/PROVEN USES**

Spray-occasions were calculated for a number of meteorological stations in England.
4. REFERENCES


Table 20  Spray-occasion criteria

<table>
<thead>
<tr>
<th>Constraint</th>
<th>Conditions</th>
</tr>
</thead>
</table>
| Operations | Daylight – but between 06 GMT and 20 GMT  
Temperature > 1°C  
No standing water, glaze, frozen ground or snow lying at 12 GMT  
Visibility > 100 metres  
Spray period – 5 consecutive hours |
| Sprayer    | Wind speed > 2 knots (about 1 ms⁻¹) and wind speed > 9 knots (about 5 ms⁻¹)  
(Wind speeds are measured at 10 m above ground) |
| Vehicle    | For Conventional vehicles the Soil Moisture Deficit using a bare soil model must exceed 5 mm |
| Chemical   | Chemical Type* |
|            | R  | C  | CH | H  |
| - Temperature | > 1°C next night  
Day maximum 10°C | 0  | 0  | 0  | 0  |
| - Relative Humidity | > 80% if temperature 10°C  
< 95% | 0  | 0  | 0  | 0  |
| - Rain | < 1 mm in any hour | 0  | 0  | 0  | 0  |
|          | < 0.1 mm in any hour | 0  | 0  | 0  | 0  |
|          | < 0.1 mm in each of 3 hours after spraying | 0  | 0  | 0  | 0  |
|          | < 2 mm total in 9 hours commencing 3 hours before spraying | 0  | 0  | 0  | 0  |

* R = Residual  
C = Contact  
CH = Contact-hormone  
H = Hormone

(0 indicates that the specified criterion must be satisfied)
3.5 Frost protection methods

Frost may be divided into three types: (a) Radiation frosts which occur on clear nights with little or no wind when the outgoing radiation is excessive, (b) Advection frosts which occur at any time of the day or night, irrespective of the state of the sky due to introduction of cold air to a site accompanied by strong winds, and (c) Combined frosts which occur when both processes are combined. Protective measures are most effective against the radiation frost.

All the methods for protecting plants fall into two main groups: (a) direct or active methods and (b) the indirect or passive methods. The direct methods are mainly aimed at improving the thermal regime of the surface layer of air at the ground and at decreasing the radiation loss from the soil and from plants. Amongst the many indirect or passive methods which may be employed, the most important are the selection of frost-resistant varieties, the proper selection of the location of the crop and the time of growing. Solanum tuberosum possesses very little or no frost tolerance while a number of wild species (S. acaule, S. chomatophilum, S. commersonii, S. multidissectum) are considered to be frost tolerant. The level of frost hardness is highly correlated with the elevation of genotype origin (Li, 1977; Palta and Li, 1979; Li et al., 1980). The freezing temperature of the species S. tuberosum is about -1.7 C (Rosenberg, 1974).

The direct methods for frost protection are the following:

1. Radiation control: Various protective covers (from glass or plastics), artificial fog and smoke (burning tyres or combustion of waste material and use of chemicals) have been used to reduce the radiation losses. The most advisable method of protecting plants from advection frost is by covering them with plastic tunnels, beneath which temperature remain 2 to 3 C higher than in the ambient air. The temperature effect produced by different kind of smoke generation methods ranges between 2 and 3 C depending on wind speed and humidity and the size of the particles of the smoke, the ideal diameter of which is about 10 μm. Foam covering (purified protein, gelantin) was found very effective under radiation frost conditions.

2. Soil heat control: There are two basic approaches to control soil heat for frost protection. Firstly, mulches can be applied to the surface. The mulching materials (hay, straw and leaf leater) should be applied in the evening of a frost-risk night. This method is effective if the protected crop is near the ground surface like strawberries, or potatoes during their early stages of growth. Secondly, crops can be protected through irrigation 2-3 days before the appearance of the frost. The temperature effect of this method is about 1 to 2 C.
3. Latent heat control: Sprinkling has become widespread as the most effective methods of protecting crops (potatoes, tomatoes, peppers, beans, artichokes and flowers) against frost. Provided that the spraying is continuous the temperature will stay close to 0°C. The sprinkling rate must be high enough for reliable protection (about 2.5 - 3 mm h⁻¹). Sprinklers should also produce fine droplets of spray (with very fine nozzles). Some workers consider that sprinkling must be begun while temperatures are still above zero and stopped when the air temperature is steadily maintained above 0°C. Others consider that to conserve water, the system can and must only be switched on at lower, sub-zero temperatures, depending on the freezing threshold for different types of plants. Experience has shown that up to 5°C frost protection can be achieved by spraying methods, roughly twice as effective as most other methods.

4. Sensible heat control: The mixing of the lower cold-air layers with the warmer ones above can raise the temperature in the surface layers by 3-4°C. If air temperature is to be kept at a certain level, mixing must be continued without interruption right up until the end of the frost period. Suitable mixing can be provided by large motorized fans. These are only effective during radiation frost. If the wind speed is greater than 2 m s⁻¹ the system is not recommended. The protected area by one fan ranges from a minimum of 2 ha to a maximum of 5 ha.

5. Direct heating: The final approach is to supplement the natural energy balance with heat released by combustion. This can be achieved by different kinds of heaters. Small heaters are preferable, because large ones may heat small volumes of air excessively. The cost of different heating methods can be considerable. The method can raise the temperature of the air by 3-4°C.

References


4. HARVESTING, STORAGE AND TRANSPORT

Both the time of planting and harvesting depend on the soil conditions (soil temperature and soil moisture) and the prevailing weather conditions. Therefore, any method which can be used to estimate soil temperatures and soil moisture during the planting time is also applicable during the time of harvesting. Details about the methods of estimating soil temperatures and soil moisture are given in sections 2.1 and 3.2 respectively.

Regarding storage and transport, temperature and humidity in the storage systems play a fundamental role in minimizing yield losses. A model was developed in England to simulate store temperatures based on the readings from ambient temperatures.

4.1 Simulation of potato store temperatures

1. OBJECT OF METHOD

1.1 Objective:

1. To simulate temperature changes in potato stores.

2. To reduce the temperature of potatoes placed in store in mid-September at a temperature of 15 C to a target temperature of 4.5 C and to maintain a bulk temperature of between 2 C and 6 C until mid-May.

2. DESCRIPTION OF METHOD

2.1 Output (expected results and accuracy)

Estimation of bulk temperatures

2.2 Description

Each hour, the decision whether or not to ventilate is made by comparing the calculated bulk temperature with the target temperature and that of the outside air. The outside air temperature for each hour is estimated by applying mathematical relationships to the observed values of daily maximum and minimum temperatures from a nearby meteorological site. After allowing for the various heat exchange processes, the bulk temperature at the end of the hour is estimated - this temperature is then used as the initial bulk temperature for the next hour's simulation.
When auxiliary refrigeration is available, it will be used to cool the residual air inside the store. This air (assumed to be at the same temperatures as the bulk) will be cooled to not more that 4.5°C below the bulk temperature - but not colder than -1°C - and then recalculated to control the bulk temperature. The following assumptions are taken into consideration in order to estimate store temperatures:

1. The potatoes are stored in bulk to a depth of between 3 and 5 m.

2. The metabolic (respiration) heat output of the potatoes is such that, in the absence of and cooling by ventilation, the temperature of the stored bulk will rise by 1°C in about 3 days.

3. Ventilation of the bulk is at a rate of 170 m³t⁻¹h⁻¹, equivalent to 100 cfm per ton.

4. The temperature of the ventilating air should be between 2°C and 4.5°C colder than the bulk but not colder than -1°C.

5. The temperature of the ventilating air is raised by 1°C due to passage through the fan system.

6. The internal wall is at the same temperature as the ambient air (i.e. no insulation). Later this assumption was modified using the following relationship:

\[ T_w = T_s + c(T_a - T_s) \]

where \( T_w \) = the internal wall temperature, \( T_s \) = the mean stack temperature, \( T_a \) = the ambient air temperature and \( c \) a constant = 0.25.

2.3 Input data

Meteorological data: Maximum and minimum air temperatures.

Management data: Thermal insulation U-values.

2.4 Operational requirements (including computer requirements)

Microcomputer.

2.5 Validity, limits imposed by basic concept, constraints in application

Calculated stack temperatures were close to those measured when the modification of the assumption of the wall temperatures was incorporated in the model.
3. REFERENCES


PART II: Requirements in Agricultural Meteorology in the Highly Industrialized Areas with Developed Agriculture

(Co-ordinators: Mr. W. Lablans, Mr. J. Lomas and Mr. T. Gorski)
Requirements in Agricultural Meteorology in the Highly Industrialized Areas with Developed Agriculture

1. Introduction

The terms of reference (c) and (d) assigned to the group were taken up together for study as they were closely related.

The group established a very close co-operation with the CAgM co-rapporteur (Mr. Dommermuth) on a similar assignment, who studied the problem on a global scale.

This study carried out for Region VI did not make any distinction between developed and developing countries. The two main reasons being:

(i) In the WMO Regional Association VI - Europe, there are strictly no developing countries as defined by the UN (e.g. by the per capita income);

(ii) As the study concerned highly industrialized areas, which naturally could be found both in the developed and in the developing countries.

2. Requirements on the adaptation of agrometeorological services to the stress factors experienced by agriculture in the countries of RA VI

2.1 Environmental pollution - a double-edged sword

Agriculture could no longer be excluded from the list of cities, industries and other services of national economy, as the main sources of pollution of the environment, and especially of the rural areas in the country. Rightfully, agriculture is now held responsible for a good part of the pollution of air, soil and water. Environmental pollution has become for agriculture a double-edged sword. Countermeasures against the degradation of the environment requires a multi-disciplinary approach.

It is therefore important that the agrometeorological sections of National Meteorological/Hydrometeorological Services are consulted on the meteorological/hydrometeorological aspects on research projects and other activities aimed at mitigating the adverse effects of environmental pollution that occurs from a competition for the use of natural resources of air, water and soil.

2.2 Crop protection and crop nutrition

The crop protection activities have been relying, until now, mainly on the use of chemicals, many of which have a negative impact on the biosphere and on the natural environment in general. This negative effect becomes even more pronounced in the areas which are already under the heavy stress of air pollution due to other causes.
Here the plants are handicapped by the long-lasting effects of high concentration of emissions and any unwise use of additional chemicals in crop protection activities may cause damage to the crops, including its quality and yield. Agrometeorological advisory services are therefore essential for crop protection activities. There is already a distinct tendency to restrict indiscriminate application of pesticides, herbicides, disinfectants and fertilizers (including manure).

It is necessary to apply the chemicals at the minimum required rate, and to take all possible measures to ensure that its protective effects are fully realized. Agrometeorological information will be most useful in this respect.

First of all, the chemicals should be applied only when and where they are really needed. Use, blindly following a simple calendar schedule should be avoided. The Meteorological Service should issue weather-based information and possibly forecasts of the onset, duration and end of weather conditions convenient for the outbreak and spreading of pest and diseases of main food and cash crops should be given. A first step in this direction could be the "negative" forecast, which eliminates the unnecessary use of chemicals in the periods with no risk of pest.

Positive forecasts take into account past and present weather conditions, and together with expected (forecast) weather, give information or advice on the favourable conditions for the onset/development/spread of pathogens.

In addition to the meteorologically-based information/forecast on the occurrence of pests and diseases, short-term weather forecasts for the operational activities, such as for spraying, dusting, or for the spreading of fertilizers, are of particular interest to highly polluted areas, because of the risk of blow away of the chemicals by wind, their splash down by rain, or the leaching of fertilizers by melting snow, etc. Specially designed weather forecasts help to reduce losses of chemicals applied and reduce the contamination of natural environment. It is evident that these services are specially of high value in the industrially polluted areas.

The importance of avoiding the flow of unwanted chemicals into the surroundings is often emphasized by the use of low volume and ultra low volume chemicals of high toxicity.

2.3 Quality versus quantity of the yield

Any recommendation concerning the requirements of agrometeorological services of highly industrialized areas should pay particular attention to the promotion of quality aspects of the produce.

Economic returns of agriculture depend highly on the quality of the product - the sanitary aspects. Often high yields are attained at the cost of quality: over-production leads to pollution of soil, water and air, to unacceptable levels. This does not mean that high yields do not deserve full attention.
In many countries, a high yield per hectare is still required to satisfy the quantitative demand of one or other products. From more sophisticated reasoning (De Wit, 1988), it follows that as soon as adequate market regulating conventions are established, for several crops a combination of high quality and high yield (per unit area) will be the best choice for agricultural land use. A prerequisite for this option is, however, that advance growing techniques are (made) available so that the intensive cropping can be executed without an overburden of the soil with chemical additives and/or a loss of quality of the produce. The agricultural meteorologist will therefore be asked to adapt his services to various new agricultural practices, replacing the traditional often too narrow systems of crop rotation.

A combination of high quality and high yield cropping systems on the best suited areas, and utilization of excess lands for forestry and other purposes, is one way of mitigating the negative impacts of agricultural over-production.

2.4 Meteorology and farm work planning

The meteorological information and advice in the day-to-day operational decision-making of the farmer has been gaining more and more importance.

Agricultural meteorologists should promote the dissemination and use of regional short- and medium-term weather forecasts for farm work planning and operational applications. Apart from the direct benefit for the farm work, such a service can contribute to the timely, effective and restricted use of chemicals and avoid overuse of manures.

Agrometeorology also can assist in the most economical use of limited water resources for irrigation, make the best use of agricultural machinery available, and help minimize soil degradation and erosion, etc.

The development of methods of weather forecasts and the extension of period covered by the forecasts up to five to six days ahead has shown that the application of medium-term weather forecasts can bring most positive effects in the farm operations and management. (Wijngaard 1988).

The development of the highly efficient systems for dissemination of meteorological information and advice is very important, especially in the regions of high anthropogenic stress, where the decision-making of the farmer is much more difficult than in the comparatively cleaner, unpolluted areas.

A number of studies on the application of meteorological and climatological information to agriculture have been published in the past decade (ranging from day-to-day farm work planning, to the climatological suitability of a region for a specific crop).
2.5 The introduction of modern technology

Well established methods of data handling and dissemination of advisories should enable the introduction of new technological tools, without much difficulty.

In meteorology, as well as in agronomy, computerized technology is being introduced at a very rapid pace. In addition, the introduction of new communication techniques, such as computer-computer links for the transfer of information available to the final user, has made the transfer of technology easier and more rapid. The absence of efficient communication channels has for a long time been an important bottleneck for such a transfer and further application of meteorological information to agriculture.

It should however be kept in mind that the interaction of meteorological factors with the biotic and chemical factors which determine the development of a crop, its pests and diseases, and the final yield, is very complex in nature. The application of automated and real processes will therefore require the control and intervention of the human element for an extended period of time. This also implies that updating of programmes of education and training should be continued.

2.6 Work-load versus manpower in agricultural meteorology

In most of the countries in the region, the activities in agricultural meteorology to be carried out are far below the capacity of the available manpower. It is essential therefore, to deploy the available manpower to the development of new services and research, especially in the regions of heavy anthropogenic stress, allotting the routine duties to other personnel available in the service.

2.7 Education and training

Education and training in agricultural meteorology traditionally has always been carried out with a small number of specialists.

This situation is no longer adequate to the present day’s requirements. The agricultural community should start to realize that the physical environment of plants and animals plays an important role compared to the biotic and chemical aspects of growing of crops and animals.

Education and training in the application of meteorology to agricultural practices should therefore be given to all levels of agricultural professionals. Only a good understanding by the final user of the processes involved will guarantee that advisory services rendered achieve the desired objectives.
2.8 Agrotopoclimatology

Agrotopoclimatological studies are essential for the accurate assessment of suitability of a region or a site for the introduction (or maintenance) of a certain farming system, or for the efficient growing of a crop, or for economic breeding of animals.

Non-climatological factors often are decisive factors in the decision-making process; the availability or suitability of a land for agricultural purposes takes precedence over climatic factors. For example, the concentration of pollutants in an area may affect the sanitary quality of a crop, although the other conditions are extremely favourable for its growth.

Meteorological/hydrometeorological information are also of use in the highly polluted areas, in the solution of problems relating to soil amelioration, drainage, reforestation, soil erosion, water management, etc.

A climatological survey alone should not therefore be attempted in such areas. A multi-disciplinary approach should therefore be recommended.

2.9 Phenology

The working group did not consider that sufficient expertise was available within the group to formulate detailed recommendations on phenological observations required under stress conditions. Continuation of classical observations is to be recommended, as the availability of long and homogenous time series could be of great value, e.g. for studies on long term changes of the environment. However, new types of phenological observations such as on indicator plants chosen in relation to new stress factors, may be essential. Phenological observations of pests and diseases of plants and animals in these areas may also be of considerable value.

3. Extract of replies from Member-countries of WMO requirements of agrometeorological services

A. AGRICULTURAL AND METEOROLOGICAL SERVICES FOR AGRICULTURE UNDER HEAVY ANTHROPOGENIC STRESS (MAINLY OF HIGH AIR POLLUTION)

(i) Belgium

The effects of atmospheric pollution on agriculture by de Temmerman, et al., (1987) concludes that:

- The effect of acid deposition on agricultural crops in Belgium does not seem to be of much significance.

- Episodes of augmented occasional ozone concentrations have adverse effects, especially in vulnerable cultivars.
SO₂ in the atmosphere has an adverse effect for some cultivars, wheat, grasses and clover, in periods of low physiological activity (winter-time).

More research is needed on the combined effect of various pollutants which may be present simultaneously.

The existence of operational services to mitigate the above-mentioned adverse effects, is not mentioned.

(ii) Canada

Most significant, unexpected visible damage is noticed in tree species, both conifer and hardwood, in eastern North America and in all regions of Canada. The dieback of sugar maple has been extensive, particularly in the provinces of Quebec and Ontario. Other species showing visible evidence of decline are oak, red spruce, Balsam/Fraser fir, Norway spruce, white birch and eastern white pine.

The decline problem is a complex one and the causes are not really understood. Air pollution is considered to be a contributing factor. Natural causes such as disease, insect and climate, are all involved.

Incidence of industrial pollution causing visible damage (loss of yield or total loss of crops) to agricultural crops have occurred in Canada.

Ozone is one of the most important air pollutants involved in crop damage. Air masses carry ozone and its precursors over long distances and affect crops in rural areas, remote from pollution sources. The southern portion of the province of Ontario is most adversely affected by ozone. Other areas of concern are: the cities of Vancouver, Montreal, Quebec, Halifax and Saint John.

In southern Ontario, damage has been observed on white bean, tomato, potato and tobacco. It has been estimated that the average annual loss for ozone-sensitive Ontario crops based on 1980 economic values, is in excess of $20 million.

Experimental studies have shown that decreasing yields of susceptible species occur with average O₃ concentrations between .05 and .1 ppm for 6 to 8 hrs/day.

(iii) Czechoslovakia

Generally, all crops are damaged to a varying extent; the damage increases with the duration of pollution.

The basic indicator of industrial air pollution is the SO₂ content and its average annual concentration in μg SO₂ m⁻³.
At average annual concentrations less than 20 \( \mu g \) SO\(_2\), practically no damage occurs. Visible damage begins to appear at concentrations higher than 40 \( \mu g \) SO\(_2\) m\(^{-3}\). For concentrations above this level, zones of SO\(_2\) concentrations and the degree of damage corresponding to them can be established:

<table>
<thead>
<tr>
<th>Zone</th>
<th>Zone Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>40 to 50 ( \mu g ) SO(_2) m(^{-3})</td>
</tr>
<tr>
<td>2</td>
<td>50 to 70 &quot;&quot;</td>
</tr>
<tr>
<td>3</td>
<td>70 to 100 &quot;&quot;</td>
</tr>
<tr>
<td>4</td>
<td>100 to 150 &quot;&quot;</td>
</tr>
</tbody>
</table>

These average concentrations of SO\(_2\) cause reduction in yields as shown below:

<table>
<thead>
<tr>
<th>Crop</th>
<th>Reduction in Yield %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Zone 1</td>
</tr>
<tr>
<td>Winter wheat</td>
<td>7</td>
</tr>
<tr>
<td>Spring barley</td>
<td>6</td>
</tr>
<tr>
<td>Legumes</td>
<td>10</td>
</tr>
<tr>
<td>Rape</td>
<td>3</td>
</tr>
<tr>
<td>Potato</td>
<td>20</td>
</tr>
<tr>
<td>Sugar beet</td>
<td>13</td>
</tr>
<tr>
<td>One-year forage</td>
<td>8</td>
</tr>
<tr>
<td>Ensilage maize</td>
<td>16</td>
</tr>
<tr>
<td>Other forage</td>
<td>12</td>
</tr>
<tr>
<td>Meadow and grazing land</td>
<td>4</td>
</tr>
<tr>
<td>Cabbage</td>
<td>15</td>
</tr>
<tr>
<td>Carrots</td>
<td>8</td>
</tr>
<tr>
<td>Onion</td>
<td>11</td>
</tr>
<tr>
<td>Cucumbers</td>
<td>11</td>
</tr>
<tr>
<td>Hops</td>
<td>8</td>
</tr>
<tr>
<td>Apples, pears, plums</td>
<td>8</td>
</tr>
<tr>
<td>Cherries, sour cherries, apricots, peaches</td>
<td>14 on average</td>
</tr>
<tr>
<td>Grapevine</td>
<td>17 on average</td>
</tr>
</tbody>
</table>

Reduced yields of produce, low in quality, is also observed. For instance, forage crops have a lower content of N compounds, higher content of dust and other undesirable elements (heavy metals); with sugar beet, a lower sugar content is observed.

In general, cereals are not damaged much. In root crops, the negative effect of reduced yields is compounded by their low quality. The greatest damage seems to occur to crops with larger leaf surfaces and a long vegetation season.
It would seem therefore that cereals are the most suitable crops for areas suffering from immissions. However, it should be noted that an increased percentage of cereal crops could result in a more intensive process of soil degradation.

Recommendations have been made for the cultivation of suitable crops in these areas:

Cereals

-------

Increase percentage of winter barley (feed) at the expense of spring barley (malt) which is more sensitive. Reduce cereal production for direct consumption.

Sugar beet

---------

Sugar beet acreage should be reduced when the yield in three consecutive years shows reduction due to immissions.

Potato

-------

Potatoes are very sensitive to immissions. Their cultivation at higher pollution levels has not been successful. Cultivation should therefore be transferred to unpolluted areas.

Hops

-----

Immissions have a strong negative impact on both the yields and the alpha-acid content. Change in area of cultivation is recommended.

Forests

-------

The first damage to forests was observed in the last decades of the 19th century. However, since the beginning of the 1980's, symptoms of damage have been observed quite regularly.

The extent of damage is regularly assessed by forest management measures. The data on the spreading and development of damaged areas are available from 1959.

The international co-operation programme for monitoring pollution impact on forests is also in vogue.
A distinct negative effect can be observed on all species of forest trees; quantitative data are only available for spruce and pine, for which production losses and mortality as related to pollutant concentration and duration, are known.

Sensitivity of species in descending order is:

1. Silver fir  
2. Norway spruce  
3. Scots pine  
.
.
(n-1) Yew tree  
(n) Limba

- abies alba  
- picea abies  
- pinus silvestris  
- taxus baccata  
- pinus cembra

On the basis of quantitative relations between pollutant concentration and duration and spruce sensitivity (spruce monocultures predominate in Czechoslovakian forests), four risk zones have been determined:

a) Forest viability less than 20 years  
b) Forest viability 21 to 40 years  
c) Forest viability 41 to 60 years  
d) Forest viability 61 to 80 years.

(iv) Denmark

In Denmark precipitation radar imagery is disseminated to the individual farmer to enable him to include this form of nowcasting in his short-term work planning.

This is an example where new technology enables the establishment of a new service, which requires in turn considerable insight of the end user in the meteorological processes and the observation techniques involved.

(v) Finland

In Finland, some losses in yields of forest production have been detected. These losses are found to be connected with the pollution from lumber and steel industries, and are thought to be of domestic origin (>60%). Coniferous trees (Norwegian pine and spruce) are the most sensitive species. The damages have been observed visually. Remote sensing techniques have also been used recently.

The impact of acidification of air, soil and water is now systematically investigated in a six year research programme "HAPRO", scheduled for 1985-1991.
(vi) Ireland

Except for localized damage from certain point sources, there is no firm evidence that forests in Ireland are not affected by atmospheric pollution (Carey, 1987). Until forest health surveys are carried out, it is impossible to quantify such effects.

The overall sensitivity of species grown in Ireland is as follows (based on Kozlowski and Constantinidou, 1986):

<table>
<thead>
<tr>
<th>Broadleaves</th>
<th>Conifers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ash (Fraxinus excelsior)</td>
<td>Silver fir (Abies alba)</td>
</tr>
<tr>
<td>Rowan (Sorbus aucuparia)</td>
<td>Norway spruce (Picea abies)</td>
</tr>
<tr>
<td>Sycamore (Acer pseudoplatanus)</td>
<td>Scots pine (Pinus sylvestris)</td>
</tr>
<tr>
<td>Beech (Fagus sylvatica)</td>
<td>European Larch (Larix decidus)</td>
</tr>
<tr>
<td>Oaks (Quercus petraea and Q. robur)</td>
<td>Sitka spruce (Picea sitchensis)</td>
</tr>
<tr>
<td></td>
<td>Lodgepole pine (Pine contorta)</td>
</tr>
<tr>
<td></td>
<td>Douglas-fir (Pseudotsuga menziesii)</td>
</tr>
<tr>
<td></td>
<td>Western red cedar (Thuja plicata)</td>
</tr>
</tbody>
</table>

(Increasing sensitivity)

Grass and forestry are occasionally affected but there have also been reports of damage to cereal. The percentage of crops affected is small, mostly localized in Ireland.

(vii) Italy

The effect of air pollution on agriculture is studied only in the administrative region of Emilia-Romagna, which is located in the south-eastern part of the Po river valley. Emilia-Romagna is an important crop producing region and also an important industrial region; effect of pollution, both from industrial and agricultural origin, is noticed.

Ceramic tiles industries produce high quantities of fluorine and dust in the smoke emissions. Fruit and vine crop production came to a virtual stop in these areas due to pollution effects. Severe damage to cattle were also reported because of fluorine and lead contaminated fodder.

A monitoring network of rain and dust gauges have been deployed by the Department of Environment, which is being automated.

No other negative acid rain effects on both agriculture and forests are signalled.
The Netherlands

Worth mentioning on the impact of stress factors on agriculture in the Netherlands, is the quantification of the effects of air pollution by Van Eerden (1987), who estimated the reduction in yield of various crops due to atmospheric pollution, as follows:

- 5% overall
- 3.4% due to ozone
- 1.2% due to SO2
- 0.4% due to HF

To mitigate these effects, some services are in operation and others are in the formation for which meteorological advisories play a part:

- An interdisciplinary service, including national meteorological service, exists to suppress emissions of air pollution when predetermined levels of pollution are exceeded, or when forecasted meteorological conditions are favourable and may persist for a significant period of time. The suppression of emissions pertains mostly to industrial and power plants' pollution; an instance of application of chemicals for soil treatment in agriculture is also reported.

- An arrangement is made for the refunding of damage due to air pollution above certain thresholds. Occasionally, meteorological data are applied to investigate the origin of the pollution.

Agriculture, industries, automobiles, etc., all contribute to pollution and its damage. It is therefore imperative that cases of actual damage will not only be financed from the funds of these services of pollution, but also for the development and execution of measures for the prevention of such damage in the future.

The present level of stress factors experienced by agriculture, whether it be of a physical nature or of an economic origin, requires an increasing degree of sophistication in decision-making on farm operations; such a decision-making process should be supported by "tailor-made" user meteorological services.

In the Netherlands, detailed forecasts are prepared six times per day for a 36 hour period; weather factors of interest for agriculture are included. A further outlook in less detail is given for a five-day period. Recently, Wijnjaard (1988) has studied the effect of introducing the medium-range weather forecast (five days ahead) in computer programmes for farm work.

Turkensteen and Lablans (1987) have recommended the development and use of agrometeorological advisory services for potato crop protection.
Major agricultural crops in the UK are unlikely to be damaged directly by current rural concentrations of sulphur dioxide and nitrogen oxides. However, in most summers, concentrations of O₃ occurring in some areas of southeast England are likely to reduce yields of sensitive crops. Recent evidence suggests that interactions between pollution and other stresses, such as pests, may be extremely important in influencing crop yields. However, on present information, it is not possible to make precise assessments of effects of pollutants on national crop yields.

Crops vary considerably in their sensitivity to toxicity caused by metals. Most horticultural and root crops are more sensitive than cereals, which in turn, are more sensitive than grasses.

There is no evidence that grasslands or arable crops in the UK are damaged directly by acid rain but there is considerable evidence from research in the UK and elsewhere, that these crops are sensitive to gaseous pollutants.

**Cereals**

Experiments in which cereals in the field and laboratory were exposed to controlled concentrations of gaseous pollutants have shown that yields are reduced without visible damage by sulphur dioxide and/or its mixtures with nitrogen dioxide at concentrations above 40 ppb. Although these concentrations are higher than mean annual rural values, they may be equalled or exceeded at many sites for periods of very short duration. Pollutants are found to reduce frost resistance and winter hardiness in cereals. Growth rates of pests such as aphids, are stimulated by pollution. Fungal diseases are promoted or suppressed, depending on the type of pollution.

**Horticulture**

Visible symptoms resembling O₃ injury have been observed in the field on species such as spinach and petunia, which directly affect its economic value.

In rural areas of southeast England, air quality reduces the yield of experimental plots of peas, beans and spinach in most summers; the effect was related to atmospheric ozone concentrations. Recent evidence also suggests that with the combined effects of ozone, sulphur dioxide and oxides of nitrogen, pea yields decreased progressively along a transect from rural areas into London. The growth of wheat and broccoli was not affected during the experiments.
Industrial pollution has caused damage to agriculture in some instances. Old mines (now abandoned) have left some surface soils enriched with lead compounds. Repercussions in terms of human health is not known. Due to existing mines, some pollution, principally lead and zinc, occur. However, pollution in Northern Ireland from industrial sources, pesticides, etc., is generally low.

Although there is no evidence at present of pollution-related forest decline in the UK, forests are being subjected to polluted environments, which are likely to cause stress. Isolated trees in urban areas may also be affected in due course. Surveys are therefore recommended for diagnosis of pollution damage.

It is still not clear what role, if any, acid deposition plays in forest decline, but three major hypotheses involving acid deposition have been proposed:

a) acidification of soils leading to loss of nutrients, aluminium mobilization and root damage;

b) exposure of foliage to pollutant gases and acid mist:

c) interactions between stress caused by acid deposition and other stresses.

There is also no evidence that UK grasslands are directly damaged by acid rain.

An experiment carried out in the summer time in a rural area of Southeast England, where pollution, due to photochemical O₃ occurs, has shown that the proportion of clover to grass in a sward is reduced, which has implications on the forage quality.

Controlled experiments on grasses in the 1970's showed that concentrations of SO₂ exceeding 30 ppb affect growth without visible damage. Annual mean ambient SO₂ concentrations in rural areas are currently five to 15 ppb and so pasture grasslands are unlikely to be affected by SO₂. However, SO₂ concentrations with higher concentrations for relatively short periods, could be damaging.

Evidence from a limited number of species indicates that exposure during winter, to concentrations of 40 ppb SO₂ together with 40 ppb NO₂ during summer, has lesser effect.

Effects of the pollutant mixture in general are far greater than the effect of SO₂ alone and can be additive for some species and synergistic for others.

There are indications from several sources that O₃ can increase leaching of nutrients which, if substantiated, could have serious long-term consequences in nutrient deficient eco-systems.
Blanket bogs are reported to have been damaged by the sulphur and nitrogen deposition which has occurred since the onset of the industrial revolution. Little is known about the effects of increased deposition of nitrogen compounds, including ammonia, in upland areas.

Surveys of the health of forest plantations (Sitka spruce, Norway spruce and Scots pine) in the UK made by the Forestry Commission since 1984, have not detected damage that could be attributed unequivocally to air pollution. The most recent (1986) survey suggests a worsening of tree conditions in all three species but causes have not been identified. Similar surveys of beech in 1985 and 1986 have shown no unusual damage symptoms.

In the most recent survey, increased needle loss was noted, particularly in the older Norway spruce. 1986 was a year with periods of unusually severe weather and heavy attacks by fungi and insects occurred, and the Forestry Commission concluded that natural factors were more likely to be responsible for increased needle loss. However, it was not possible to rule out the influence of air pollution.

The Forestry Commission survey in 1985 and 1986 showed no symptoms of poor health in beech.

Surveys of this type cannot establish causes. Investigation of a number of diagnostic tests indicative of pollution stress is needed. These include measurements of leaf surface, biochemical and physiological factors. A recent multinational pilot survey in Europe has shown that some of these tests can identify significant differences between trees growing at different sites, which experience a range of pollution concentrations.

B. WATER POLLUTION, MAINLY FROM ATMOSPHERIC POLLUTANTS

(i) Canada

Water resources (rivers, lakes and water storage facilities) are affected by atmospheric pollutants.

There has been an increase in sulphur and acidity in the surface waters of most of eastern Canada over the past several years as a result of industrial emissions of SO₂. Surface water alkalinity has been lost; increased sulphate concentrations have been observed.

Repeated and extensive fish surveys in eastern Canada continue to confirm that species' diversity and richness are reduced in acidified surface waters.

The case study of lakes in the Lacloche Mountain Range, 65 kilometers southwest of the Sudbury smelters showed that fish in this region stop reproduction at pH 6 - 5.5 - Smallmouth bass, Walley Burbot; pH 5.5 - 5.2 - Lake trout, Troutperch; pH 5.2 - 4.7 - Brown bullhead, White sucker, Rock bass; and pH 4.7 - 4.5 - Lake herring, Yellow perch, Lake chub.
In southwestern Nova Scotia, losses of Atlantic salmon populations have been documented in several rivers, and serious reductions in harvest have been noted in others.

Algae and zooplankton populations decline at pH values below 6. Mayflies, common snails, and benthic crustaceans are also very sensitive to low pH.

Field and laboratory experiments have shown that acidic water conditions, particularly waters with pH less than 5, are toxic to amphibians.

Waterfowl breeding appears to be lower in acidified streams where prey organisms are limited by nutrient availability as well as low pH.

(ii) Czechoslovakia

Pollution acts along two basic lines:

a) It affects vegetation and soil, thereby influencing the hydrological balance of a given catchment. Destruction of the vegetation canopy reduces the retention and retardation capacities of a catchment, increases surface runoff and erosion, and consequently, the silting of water reservoirs. Water regime in reservoirs is affected by the great fluctuation in the discharges of inflows.

b) Pollutants are directly absorbed from the atmosphere by water reservoirs, as well as transported from soil to water. The contamination caused by pollutant wash-out from soil greatly exceeds that due to direct absorption and that due to acid precipitation incident on water in reservoirs.

In Central Europe, water reservoir contamination by airborne pollutants (whether direct absorption or transport from soil) occur only in isolated cases (e.g. in small mountain lakes having no economic importance). As for larger reservoirs, pollution originating from the air is quite negligible in comparison with industrial pollution brought to water streams.

Studies or water pollution due to airborne pollutants and their effect on fish and other biological activities, have been scarce so far.

(iii) Finland

Acidification of small lakes in both southern and northern Finland have been detected. Long-range transport of SO2 and NO2 seems to play an important role here, the sources of pollutants being from the SW and SE directions for southern Finland, and possibly additionally from the East for northern Finland. Local damages for fish have occurred due to chemical discharges from factories.
Ireland

Survey of Stress Factors and the Role of Meteorological Services

Introduction

Pollution from agricultural sources has increased substantially in recent years. The request for information implies that "Agriculture" is the injured party, but it is often the offending party causing stress to the environment. Figure 1 gives a graph of the fish kills in Ireland (1969-1987) from three primary sources. While the kills due to industrial pollution and sewage are relatively stable, those caused by agricultural pollution have increased considerably. Agricultural pollution was responsible for 59% of cases in 1986 and 70% of cases in 1987 (McCarthy, 1988).

Pollution arising from agricultural activities can be exacerbated or diminished by prevailing weather conditions, e.g:

a) Run-off of silage effluent from storage is strongly influenced by rainfall.

b) Run-off after spread of slurry or fertilizer application during periods of frozen ground, drought, heavy rainfall and soil moisture conditions, affect adversely.

c) Concentration of atmospheric pollutants, such as smoke, is closely correlated to wind speed and temperature.

Background to water resource situation in Ireland

The availability of water resources in Ireland is greater than that in most other European countries, due to the relatively low population and high rainfall. Since the major towns and cities with their associated industry, are situated in coastal areas, only a minimum or small fraction (20%) of the total discharge of wastes from point resources enters freshwater. The bulk of the waste discharged is organic (sewage and food processing wastes), its main polluting effects being de-oxygenation and eutrophication. The occurrence of toxic or other directly harmful pollutants is low. The generally satisfactory situation in respect of water quality in inland areas, which might be expected in view of these circumstances, is largely borne out by the results of surveys (Feny, 1985 Ia,ib, 1986) and, in particular, by the ubiquitous occurrence of the sensitive game, fish, trout and salmon.
Number of Fish Kills 1969–1987.

Figure. Numbers of fish kills from three primary sources: Industrial, Sewage and Agricultural.
Recent developments in agriculture, particularly the rapidly increasing area of silage as fodder and the intensive rearing of livestock, represent a major potential threat to the food quality of the country's inland waters. The large accounts of organic waste matter which accumulate as a result of these changed activities, have a much greater polluting power than sewage and most industrial wastes of the type generated in Ireland. Unless they are intercepted efficiently at the point of generation, stored, where necessary, in impervious receptacles, and disposed in a manner which minimizes the carry-over of pollution to surface and groundwater, such wastes are capable of causing serious pollution and large-scale loss of beneficial use of water resources.

There has been an incidence of pollution in recent years which may be attributed to the release of these wastes, directly or indirectly, to water. The most serious cases seem to be associated with silage making, where failure to intercept the liquid waste or to store it safely, has led to direct increase of the waste to surface waters, resulting in fish kills, and, on a few occasions, contamination of water supply sources. In addition, the eutrophication of several important fishery lakes has been shown to result from the spreading of livestock manure slurries on land, at rates or times which are inappropriate if the run-off of nutrients (P and N) is to be minimized (Tooneretal, 1986; Flanagan and Larkin, 1986; Water Pollution Advisory, 1983).

The potential of agricultural wastes to cause pollution in Ireland is exacerbated by the relatively high rainfall and its more or less even contribution over the year. This, on the one hand, has encouraged the change over to silage instead of hay for cattle fodder and, on the other, heightens the need to be vigilant in the interception and storage of the associated liquid waste. In addition, the ultimate disposal of this waste, and the much greater qualities derived from intensive livestock rearing, by land spreading, also has a greater potential to cause pollution because of rainfall patterns and intensity. Thus, spreading of wastes just before heavy rainfall, may lead to direct wash-off of the organic matter leading to serious pollution of adjacent lakes. In some areas of the country, the presence of clay soils creates a further difficulty for the safe disposal of wastes by land spreading: the combination of high rainfall and clay soils may restrict the time over which wastes can be applied to land without excessive leaching, to one to two months in summer. Such a restriction may be difficult to implement in practice.

(CAGM35)
List of Stress Factors

Surface Water Pollution

Surface water pollution arises from three main agricultural sources:

a) Ingress of organic wastes into water courses or lakes directly from farmyards, causing DEOXGENATION (fish kills, etc.) arise as a result of accident, ignorance or generally poor husbandry in relation to waste collection and storage.

b) Ingress of toxic agrichemicals such as herbicides, pesticides, sheep dip, etc., due to carelessness when machines are filled and allowed to overflow near streams and rivers. These chemicals are toxic to river flora and fauna.

c) Run-off of nutrients and organic matter following landspeeding of fertilizers and/or slurry, causing EUTROPHICATION.

Possible Meteorological Response to:

a) Resultant fish kills, while very emotive and attract high media profile, arise as a result of accident, ignorance or bad management. Weather forecasting would not be expected to be particularly helpful in prevention of fish kills although reviews of recent weather may help increase awareness of the potential hazard arising with effluent from silage made in poor weather conditions, and the need for proper control measures.

b) Weather forecasting will also have little import in ameliorating incidences relating to toxic waste dispersal into water courses.

NOTE: It is generally assumed that pesticides are not a problem in Irish aquifers. However, no study of trace organics in groundwaters has been made yet, so the extent to which pesticides are leached into groundwater is largely unknown.

c) Run-off of slurry/fertilizer following landspeeding is a function of (i) soil type and land use (ii) soil moisture at the time of spreading, and (iii) rainfall after spreading. Where slurry is spread with a conventional tanker, it is very unlikely to cause direct run-off on any soil type because farmers are reluctant to use machinery on wet land if it is liable to cause wheel damage. Consequently, if the soil is fit to take the
machinery, it has the capacity to accept a normal application of slurry (30,000 to 40,000 t/ha). A pig farmer with a disposal problem might be an exception to the general rule. The danger of nutrient run-off is therefore related to the weather which pertains after spreading and particularly to rainfall in the first two to three days after spreading. It is particularly important to avoid run-off within the first 48 hours after spreading (Sherwood, 1986) and weather forecasting would be a vital component in a good management plan.

Sherwood reported that run-off from land can pose a problem on the heavier soils in this country. Research has shown that the most important factor is the time interval which elapses between spreading the manure and the occurrence of the storm which causes run-off. If the rainstorm occurs within 48 hours of spreading, it is possible to lose 30% of the applied N, P, K and BOD in the run-off water from an impermeable soil, thus causing extensive pollution. If a week elapses before the rainstorm occurs, then the BOD will be very much reduced and all of the other parameters somewhat reduced. The concentration of nutrients in run-off water at different time intervals following spreading of pig slurry at 3.6t DM/ha in field experiments are shown in Table 1.

It is notable that while the BOD concentration fell rapidly, the phosphorus concentration was still 7 mg/l after three weeks, and such a level would contribute to eutrophication of lakes.

These results demonstrate that winter spreading of slurry should be prohibited in areas where there are fishing lakes.

<table>
<thead>
<tr>
<th>The interval between spreading and run-off storm (days)</th>
<th>Concentration in surface run-off water (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
</tr>
<tr>
<td>1</td>
<td>300</td>
</tr>
<tr>
<td>7</td>
<td>41</td>
</tr>
<tr>
<td>14</td>
<td>10</td>
</tr>
<tr>
<td>21</td>
<td>8</td>
</tr>
</tbody>
</table>

| Amounts applied (Kg/ha) | 268 | 70 | 131 | 1,300 |

Table 1. Composition of run-off water from storms which occurred at different time intervals following spreading of pig slurry at 3.6t DM/ha on grassland.

(CAgM35)
However, packages of information (models) are seriously lacking. Mini-models are needed for each major soil type, in relation to moisture holding capacity, hydraulic conductivity, subsoil permeability, etc. Then by feeding in data on historical rainfall and forecast rainfall, it should be possible to say whether spreading of farm wastes in late autumn, winter, spring should be allowed or disallowed (discouraged) in any particular area.

Raised Nitrate Levels

The potential problem with regard to fertilizers is one of elevated nitrate levels in groundwater (Aldwell et al., 1982; Daly, 1985; Daly and Daly, 1984; Thorn, 1986). However, nitrate levels in Irish groundwaters are generally low (a few mg/l as N, normally less than the E.C. guideline of 5.65 mg/l as N), and the widespread high nitrate problem found in the eastern U.K. and in parts of continental Europe is not found for a number of reasons, including the low proportion of tillage, the relatively low fertilizer use, and the high effective rainfall having a dilution effect. Where high nitrate levels are found, they are usually attributable to point sources such as septic tank effluent, farmyards, silage and slurry pits, etc. In areas of more intensive agriculture, such as the Fermanagh valley, there does appear to be an elevated background level of nitrate due to leaching from diffuse sources (fertilizers or natural soil nitrogen released on ploughing), but boreholes where the nitrate exceeds the E.C. maximum admissible concentration (11.3 mg/l as N), are usually found to be badly sited, close to an organic point source.

Atmospheric pollution

Atmospheric pollutant concentrations in the Dublin area have risen significantly since the late 1970's, mainly because of the increased use of coal as a domestic heating fuel. McGrath (1988) found smoke concentrations to be closely related to surface windspeed and air temperature but the connection was more tenuous for SO₂. Both smoke and SO₂ levels were found to depend on wind direction to some extent, but the effects were generally small and probably arise from differences in local exposures or from cross contamination between sites. A forecast model for smoke pollution was developed and initial results are encouraging. McGrath postulated for future developments that a more detailed knowledge of the emission sources and their variation in response to weather and season, and more detailed pollution measurements and observations of temperature and wind profiles within the lowest 100 m of the atmosphere would improve capability of model.
Rural chemical industries

Rural chemical industries cause air pollution primarily where siting of the factory has been bad (i.e. in a valley close to road/rail and water and with reduced stack heights for amenity reasons) or other reasons (Fleming and Parle, 1977; Turney, et al., 1972). Other local effects are discolouration of foliage on exposed first edges (very local) failure of tree seedlings to thrive. Abnormal growth effects in cereals have occasionally occurred. A particular local incident occurred where several farms reported failure to grow steers, loss of milk yield (30% reduction), increase in calf and cow mortality, damage to blood and liver in all animals, by exposure to airborne pollutants, including hydrochloric acid mists and unburnt waste solvents, both by inhalation of airborne material and ingestion of deposited material.

Emissions from the factory concerned were not adequately monitored or controlled, and came from stack tops at the same level as, or below the affected farms. One of the farmers affected then sued the company for damages under Common Law, and after 62 days in Court, won his case.

5. Forestry - Acid rain and Wind throw

Acid rain is not a major problem in Ireland (Carey, 1987). However, the major meteorological stress factor affecting forestry is wind. Wind throw occurs every year in plantations of all species, but is particularly important in high yielding stands of Sitka spruce growing on wet mineral soils. Wind speeds of 20 ms\(^{-1}\) gusting to 30 ms\(^{-1}\) are sufficient to cause uprooting and these occur on all upland sites.

C. SOIL POLLUTION FROM ATMOSPHERIC POLLUTANTS

(i) Canada

Soils have been affected by both industrial and agricultural pollutants due to chemical additions, sewage and industrial sludge, pesticide residues and biological contamination. For example, Cu, As, Pb and Hg concentrations in some soils have been greatly enhanced through pesticide and fertilizer use and aerial deposition, resulting from smelting of metal. Generally, heavy metal concentrations in soils increase with increasing clay and organic matter content. Such natural variations frequently exceed increases due to contamination.

Some agricultural soils have elevated levels of contaminants which are attributable to the past use of pesticides and herbicides. Biological decomposition reduces levels of these compounds; decomposition rates are influenced by soil texture and climate. Awareness of potential environmental problems together with the intensive evaluations required for the application of pesticides and herbicides has helped in reducing the extent of soil contamination by residues.
At normal application rates, some herbicides persist in the soil at phyto-toxic levels for more than a year. Cool climates and certain types of soils delay herbicide decomposition.

Biological contamination includes the golden nematode as well as a number of other soil-borne disease organisms such as clubroot in cabbage and root-rot in cereals and tobacco. Animal parasites and diseases such as coccidiosis of poultry and anthrax in cattle, although surviving for relatively short periods, can contaminate soils. Canada currently has no restriction for livestock production in soils contaminated by disease organisms.

Application of sewage sludge on land increases heavy metal concentrations in soil. Concentrations vary depending upon agricultural practices, industrial activity and large natural differences in soil composition.

(ii) Czechoslovakia

Airborne pollutants (mainly industrial) cause cumulative soil contamination. Cumulation of \( \text{SO}_4^{2-} \) and \( \text{NO}_3^- \), as well as slower cumulation of heavy metals are observed.

Acid rains cause leaching of soluble Al and Mn forms from soil. The transport of these two elements by surface and groundwater constitutes a major secondary source of pollution in water storage facilities (reservoirs) and poses a serious problem to potable water resources.

Immissions reduce production and self-cleaning capacities of soil and plant nutrition is affected even with balanced fertilizing. Apart from this, plants get contaminated by biologically undesirable elements which reduce crop quality and sometimes enter the food chain. Soil has a certain capacity to compensate the impact of immissions on crops; however, their long-term and intensive action causes, even in less vulnerable soils, damage to the physico-chemical properties and produces unfavourable changes which lower the fertility of soils.

The basic rules to alleviate the negative impacts of immissions include:

a) preserve and increase the content and quality of humus and soil biological activity;

b) modify soil reaction \((pH)\);

c) apply suitable fertilization by farm manure and industrial fertilizers.

These methods become complicated and complex by the actual intoxication which results from the broad variability of the soil cover and geomorphology.
Depending on type, soils can be categorized as to their vulnerability:

<table>
<thead>
<tr>
<th>Category</th>
<th>Soil type:</th>
</tr>
</thead>
<tbody>
<tr>
<td>vulnerable</td>
<td>light (content of particles of size 0.01 mm or below, less than 20%)</td>
</tr>
<tr>
<td>susceptible</td>
<td>medium (content of particles of size 0.01 mm or below, less than 20 to 45%)</td>
</tr>
<tr>
<td>resistant</td>
<td>heavy (content of particles of size 0.01 mm or below, over 45%)</td>
</tr>
</tbody>
</table>

Soil is affected by the increasing content of certain adverse elements depending on the distance from pollution source and the nature of atmospheric deposition, by as much as 27% in a year.

It is very difficult to compensate the negative effects of heavy metals in soil, causing plant contamination. A differentiated approach is required, respecting the properties of the deposited elements and soil and ecological conditions.

(iii) Finland

The acidity of soil of forest land has increased due to SO₂ and NOₓ deposition. In agriculture, heavy use of fertilizers and pesticides is common. However, the required amount of pesticides here is less than e.g. in the middle European countries, due to the prevailing cooler climate.

(iv) Ireland

Land use in Ireland is approximately 90% for grassland and 10% for arable land. The arable crops are mainly cereals, sugar beet and potatoes. A survey on fertilizer use by Murphy and O'Keeffe (1983) shows that the average use of N on arable crops is normally near the recommended rate for optimum use, and occasionally higher. Winter wheat and sugar beet both received 150 kg N/ha in 1982. Assuming approximately 10% of applied fertilizer N is leached and together with approximately 50 kg N/ha from soil organic matters, the resultant concentration in the estimated 500 mm per annum of leaching water would be 13 mg NO₃-N/1. It is however, assumed that 50% of nitrate is denitrified before reaching groundwater. Therefore, even in areas where there is a very high area of arable crops, the nitrate content of the groundwater should be within the limit of 11.3 mg/l of the European Economic Commission's directive.
The above mentioned survey also showed that the national average use of nitrogen on grassland in 1982 was 46 kg/ha for hay and pasture, and 105 kg N/ha for silage. However, a very wide range in fertilizer use ranging from zero N on the majority of summer grazing beef farms to 300 kg N/ha on some dairy farms is reported. Although considerable nitrogen might be expected to leach from grazed pastures receiving 300 kg N/ha, the high dilution by 500 mm leaching water, denitrification and dilution in the aquifer by water from areas which received no fertilizer, tend to ensure that the NO₃-N concentration of drinking water remains within directive limits. Groundwater supplies which have been found to contain high levels of nitrate, have always been associated with poor location of farm waste storage units or septic tanks.

(v) United Kingdom

Some soils (e.g. podzols of Northwest Wales) have already become saturated with sulphate, and further deposition of sulphate will lead to high acidity levels and aluminium concentrations in drainage water.

There are indications that acidification affects the biological activity of soils, reduces rates of litter decomposition and restricts consequent nutrient release. Soil acidification will also affect the mycorrhizal relationships between certain fungi and the fine roots of forest trees that facilitate tree nutrition. The significance of these effects is not fully established and hence an important research area for the future.

Land which has been contaminated by industrial processes or mining is very carefully assessed for toxic pollutants before redevelopment or change of use is permitted. Higher standards, that is lower levels of potentially toxic elements, are recommended for agricultural land which is used for food production, rather than for less sensitive land uses.

The disposal of sewage sludge to agricultural land is carefully monitored and controlled in order to eliminate any risks to plant, animal or human health. The Economic Council has recently produced a directive on the use of sewage sludge on agricultural land, and discussions are in progress for its implementation in the country. This is likely to require only minor modifications of present practices.

Most pesticides become inactive in a fairly short time in the soil. Chemical fertilizers are in general, costly products, and are therefore applied only when they can make an economic contribution to crop production. Animal manures are recycled to land to take advantage of their plant nutrient content and, although intensive husbandry can result in local problems of excess production, on a national scale animal wastes do not create soil pollution in the UK.
In general, most mineral elements applied to land are retained in the soil. However, as indicated above, monitoring and controls ensure that the amounts present do not create a hazard to agriculture and there has been no excessive build-up of phosphate or potassium. Nitrogen as nitrate is the only element which leaches from soil to an appreciable extent following normal agricultural practice. There has recently been concern about increasing groundwater nitrate levels, but the situation is restricted to areas where the subsoil is porous and, particularly when rainfall is low, confined to defined catchments.

D. ANIMAL HOUSANDEY

(i) Czechoslovakia

In comparison with plant cultivation, exact knowledge about the impact of immission on farm animals is low. Immissions affect farm animals both directly and indirectly.

Direct effects

These include the immediate action of immissions on the health of the animals which are temporarily or permanently exposed to polluted environment. The severity may vary considerably within a given locality. The important factors which contribute to the severity are climate and actual weather, constitution of animals, their performance, pregnancy, the quality and quantity of nutrition, the standard of shedding, etc., besides the immissions themselves. Disease caused may be acute, sub-acute chronic or sub-chronic, with different pathological symptoms. It may be manifested as want of appetite, disorders of the digestive tract, irritation of mucous membranes and anaemia. These disorders reflect in the value and reproductive abilities of animals (drop in milk yield and mass increments, infertility, birth of weaklings, etc.). In general, the effects of immissions on animals can be categorized as follows:

- respiratory syndrome:
  - cough, hyperaemia of conjunctiva and mucous membranes,
  - sneezing, hard breathing, discharge from nasal cavities;

- digestive syndrome:
  - suffocating, vomiting, diarrhoea;

- mental syndrome:
  - lassitude, lack of appetite.
Indirect effects
-------------

Large-scale intake of contaminated feed with lower nutritional value reduces yields. The impact of immissions on animal production in areas with 50 - 70 ug SO$_2$ m$^{-3}$ has been monitored for several years, and the results compared with those obtained in unpolluted areas (i.e. concentrations less than 20 ug SO$_2$ m$^{-3}$). The following conclusions have been drawn:

**Dairy cows:** Immissions caused a 19.4% decrease in milk yield, a 71% increase in pre-natal losses, and a 52% increase in peri-natal losses.

**Comparison of results obtained in unpolluted areas and in an area with 50 - 70 ug SO$_2$ m$^{-3}$ pollution**

In unpolluted areas, the daily increment in mass is higher by: at grain consumption lower by: losses and slaughter lower by:

<table>
<thead>
<tr>
<th></th>
<th>calves:</th>
<th></th>
<th>heifers:</th>
<th></th>
<th>horned cattle:</th>
<th></th>
<th>pigs:</th>
</tr>
</thead>
<tbody>
<tr>
<td>fed on milk</td>
<td>20%</td>
<td>8%</td>
<td>42%</td>
<td></td>
<td>56%</td>
<td>21%</td>
<td>12%</td>
</tr>
<tr>
<td>fed on plant products</td>
<td>25%</td>
<td>11%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Conclusion: The effect of industrial missions significantly depends on the duration of exposure of animals to pollution; this negative effect increases with the length of the exposure, which implies that in areas with immissions only certain animals should be kept and then only for short intervals, and they should be those that are not intended for breeding.

(ii) **Ireland**

A problem from fallout from a lead mine has recently been encountered and a number of animal deaths have been reported. (Tunney, et al., 1972; Fleming and Parle, 1977).

E. METEOROLOGICAL SERVICES TO AGRICULTURE IN THE POLLUTED AREAS

(i) **Canada**

The Meteorological Service does not provide a specific service to agriculture for dealing with industrial and agricultural pollution. However, some of the regional offices do provide consulting service on optimum weather conditions for pesticide application.
The Meteorological Service provides information about average, and/or actual values of SO2 emissions in different localities, and produces maps of pollution for its internal purposes. The problems of impact of industrial emissions on agriculture and forests have been, and are being, tackled by agricultural and forest research institutions.

Generally speaking, the information provided is mainly of the non real-time basis, giving a picture of the long-term regime of meteorological conditions of pollution as well as a picture of the pollution itself.

Operational (real-time) meteorological information is not currently being applied directly in agriculture or forestry, primarily because neither agriculture nor forestry is able to respond quickly enough to such information with adequate accuracy.

The information relating to the long-term planning of agricultural and forest production is transmitted to the operational and research institutions of the agricultural and forestry sectors and to the supervisory ministerial authorities. The information used for claiming the compensation from the insurance company is provided upon request to the damaged farms themselves.

Methodologies for farming in areas with industrial immission are being elaborated:

a) reduce the impacts of immission on soil through measures such as:
   - retaining and increasing the quantity and quality of the soil organic matter and of the biological activity of soils
   - modifying soil reaction
   - fertilization of soil under cultivation

b) reduce the negative impacts of immissions on plant production through:
   - selecting suitable agrotechnical measures
   - proper organization of production and protection techniques

The principles to be respected in the cultivation of individual crops are elaborated.

(iii) Germany, Democratic Republic of (GDR)

From GDR the development of an advisory service for the application of fertilizers is reported. Some new methods of plant protection are being practiced.

(CAgM35)
(iv) German, Federal Republic of (FRG)

In FRG the requirements of agricultural meteorology in countries with highly developed industries have been studied comprehensively.

In industrialized countries, agrometeorological advisories for crop should be oriented towards promoting quality, in addition to, or rather than, promoting high yields.

Environmental stress factors go along with economic stress factors and agrometeorological methods should be developed with this realization. They may form a complex pattern in which synergistic effects easily can occur.

Some stress factors exercise their adverse effects with a considerable delay in time. Advisories should not overlook this aspect. Agrotopoclimatology advisories should not only include suitable growing conditions for crops from the point of view of physical climatology, but also the viability of the location concerned for land, air and water of a suitable quality.

Also, the suitability of location with respect to possible phytopathological stress should not be overlooked.

In the dissemination of advisories, ways and means of modern communication technology would have to be introduced; it is realized that this may be at the cost of positive effects of traditional systems, such as personal contacts between the meteorologist and his client.

As items for new advisory services, the following could be mentioned:

- optimal use of water resources, which includes the assessment and prediction of evaporation
- efficient use of pesticides
- prevention of pollution of surface water and groundwater by agricultural activities such as the dumping of surplus manure under unfavourable meteorological conditions
- storage and transport of agricultural produce
- animal health. (Attention should be paid to synergistic effects of meteorological conditions on environmental pollution).

Specific attention is paid in FRG to advisories on irrigation. The demands for unpolluted water often outweighs the available resources and consumptive use of water is an urgent need. It has been calculated that each irrigation costs 120 Dm/ha. Furthermore, non-judicious irrigation leads to uneconomical use of fertilizers and their spilling in the environment. Agricultural meteorology should therefore assist in the further development of advisory services on the water-budget of the crops, including the quantitative forecasting of precipitation.
This necessitates an intensification of co-operation between agricultural meteorologists, hydrologists and agronomists.

(v) Hungary

In Hungary an interdisciplinary co-operation within the framework of a computer controlled production system for perishable vegetables is in vogue.

Agrometeorological input to the system is twofold. In the stage of development of the system, an agroclimatological and phenological survey was executed to identify the best suitable sites for the growing of the crops concerned. The operational computer-aided management system of the cultivation is supported by data supplied from meteorological observing stations of a density adapted to the requirements of the project.

(vi) Israel

In Israel the ever-growing demand for agrometeorological services can be grouped under two main headings:

A. Services for agricultural planning - such as the considerations of irrigation water amounts, optimum planting dates, choice of the best varieties, crop rotations, etc.

B. Services provided for the improvement of agricultural technology - such as the timing of irrigation, fertilizer and pesticide application and the cultivation methods, etc.

(vii) The Netherlands

In the Netherlands emphasis is laid, and experience is gained in the provision of specialized weather forecasts for agriculture as a support for decision making in farming.

Topics included in the forecasts are adapted to the season and growing stage of the crops and updated every few hours. Also the outlook for a five-day period is given. Van Eerden (1967) quantified the reduction of the results of arable farming due to air pollution in per cent of the economic yield, as follows:

- 5% over all
- 3.4% due to ozone
- 1.2% due to SO2
- 4% due to HF

(CAgM35)
Traditionally, there is an abundant supply of precipitation and surface water. However, recently water is scarce, and occasionally significant groundwater table depressions have been reported. Forecasts on evaporation and precipitation as a guidance for irrigation are therefore provided.

(viii) United Kingdom

Examples:

- rainfall return periods for design of farm waste systems - available to advisors in ADAS (the UK Agricultural Extension Service); used in the design of dirty water disposal systems to ensure adequate storage facilities.

- odour concentration calculations - available to advisors in ADAS. Item has potential for use in estimating the nuisance effect of, for example, a poultry house near an urban area where the odour may be unwelcome.

- consultancy services for spraying can be hired by the individual farmer/grower. They allow the short-term planning of spraying activities: the meteorological data is used in the analysis of incidents and for major reports on serious occurrences.

- Herbicide Leaching: the persistence of herbicides in the soil in response to temperature and rainfall can be estimated for a variety of chemicals. Information on the residual levels is used in interpreting soil samples, assessing losses, advising on herbicide injury to crops after abnormally slow degradation or on rapid degradation leading to the need for extra application.

- Dirty Water Disposal: increasing concern for the environment has meant that careful disposal of dirty water (e.g. from cattle houses) is essential. The design of pumping systems and storage tanks depends to some extent on rainfall, and information on the frequency of rainfall amounts over given durations is available for any site in the UK.

F. RESEARCH

(i) Canada

The Atmospheric Environment Service/Environment Canada is currently developing a database to archive and analyze Canadian federal and provincial atmospheric deposition data. The objectives of the database facility are listed below:
1. Data archive: The database will provide a permanent archive for all Canadian atmospheric deposition data from regional scale networks. The data will be stored in a common format regardless of source and will be subjected to a standard set of quality control procedures before being entered into the archives.

2. Standard analysis and reports: The database will perform a standard set of analysis on the data. The primary products will be standardized, and multi-network and summary reports published on a regular basis.

3. Data access: Data in the archive will be treated as public information.

(ii) Finland

The effect of pollutants on environment (soil, vegetation and lakes) is being studied in Finland in a number of projects, many of which are under acidification project "HAPRO" funded by the Ministry of Environment. A wide range of experts has been working on this topic since 1982.

The effect of O$_3$ on agriculture is being studied in the Agriculture Research Centre (ARC). Heavy metals have been noted to cause cultivation problems in restricted small areas.

A study at ARC aims at reducing chemicals used in plant protection. Advice is given from the agriculture weather service.

The chemical load caused by agriculture on rivers and lakes is being studies by the National Board of Waters and Environment.

(iii) Ireland

In Ireland, agriculture is considered as a major source of environmental pollution. The rivers and other fresh water sources are especially affected by the increased use of chemicals in agriculture, and discharge of surplus manure and effluent from silage.

Research activities planned for three main areas in Forestry in Ireland include:

a) A survey of forest health status based on a European grid system which was carried out in 1987 for the first time;

b) More detailed research on improving the understanding of mechanisms involved in the effects of atmospheric pollution on trees;

c) Use of colour infra-red photography to detect stress of all kinds.
It is proposed that meteorological data be used to compliment other types of data, particularly as regards item (b) above.

(iv) Spain

In Spain, investigation concerning the problems of erosion of soils and other forms of degradation resulting in desertification in the Mediterranean climate zone is being carried out.

(v) United Kingdom

The Meteorological Office is actively engaged in the development of computer generated forecasts for spraying.

The Meteorological Office, in conjunction with other Government Departments, has developed a model for predicting the pollutant dispersal in straw burning operations. The model has been used in the development of a new code of practice to be observed by farmers engaging in straw burning.

4. Preliminary conclusions and recommendations

The following are the preliminary conclusions and recommendations of the working group on the requirements of agricultural meteorological services in countries with highly developed industries:

- In many countries, agricultural meteorologists are confronted with a variety of new problems which arise from the competition of agriculture with industries and urban population in the use of soil, water and air.

- The problems mentioned above differ widely from the problems treated by traditional agrometeorological research and advisory services.

- The new challenges warrant the strengthening of agrometeorological units of meteorological services of Members with manpower and scope of expertise. It is possible that in some countries an urgent need is not obviously felt. However, it is important that in these countries the agricultural meteorologists are included in the multidisciplinary teams and/or at least consulted when new services are proposed for combating the above mentioned stress factors.

- Developments in agricultural meteorology require that close co-ordination be strengthened between the agricultural meteorologists and the officials of the meteorological services dealing with weather forecasting and environmental pollution problems. New methodologies and techniques may have to be introduced in the existing services. The whole of new and traditional services should make intelligent use of modern technology in the field of collection, elaboration and dissemination of data and advisories.
5. References


Ashenden, T.W., 1979. The effects of long-term exposures to SO2 and NO2 pollution on the growth of dactyliis glomerata L. and Poa pratensis L. Environmental Pollution, 18, pp. 249-258

Ashenden, T.W. and Bell, S., 1987. Yield reduction in winter barley grown on a range of soils and exposed to simulated acid rain, Plant and Soil, 98, pp. 433-437


Colvill, K. and Horsman, D.C., 1982. Field trials and open-top chamber studies of the influence of sulphur dioxide on the growth of ryegrass "Effects of gaseous air pollution in agriculture and horticulture", Unsworth and Ormrod, Buttersorths, London, p.481


Davies, T., 1980. Grasses more sensitive to SO2 pollution in conditions of low irradiance and short days. Nature, 284, pp. 483-485


Fahy, E., 1985 (a). Fish Kills in Ireland - an Analysis of incidents in 1983 and 1984, Fishery Leaflet 128, Fisheries research Laboratory, Dublin 15

Fahy, E., 1985 (b). Fish Kills in Ireland in 1985, Fishery Leaflet 132, Fisheries Research Laboratory, Dublin 15


Häkkinen, A., Jokinen, J. and Kauppinen, H., 1985. Levels of atmospheric sulphur dioxide and the main odorous sulphur compounds related to damage to coifcals trees in the Imatra area, Finnish Meteorological Institute, Helsinki, 81 p. (in Finnish)


Mulchi, C.L., Sammons, D.J. and Baenziger, P.S., 1986. Yield and grain quality responses of soft red winter wheat exposed to ozone during anthesis, Agronomy Journal, 78 (4), pp. 593-600


Sherwood, M., 1986. Leaching and Runoff of Nutrients following Land spreading of Fertilizers and Animal Manures - a literature review for the Water Pollution Advisory Council, p.44. The Agricultural Institute, Johnstown Castle Research Centre, Wexford, Ireland
Thorn, R.H., 1986. Factors affecting the leaching of nitrate to groundwater in the Republic of Ireland, Irish Geography, 19, pp. 23-32


Water Pollution Advisory Council, 1983. A Review of Water Pollution in Ireland, Department of Environment, (An Foras (Forbartha)), Dublin 2

Water Pollution from Farm Waste, 1985. England and Wales. Published by the Water Authorities Association Publications, St. Peter's House, Harthshead, Sheffield S1 1EU


(CAgM35)
PART III: AGROMETEOROLOGICAL DATA BANK

(Prepared by Mr. V.N. Poleevoy and Mr. J. Müller)
AGROMETEOROLOGICAL DATA BANK

The report of the session of the WMO Working Group on Data Requirements for Agriculture (1980) offers excellent background material for discussion on the establishment of an Agrometeorological Data Bank. Although this report is 10 years old, it provides information on different meteorological elements required for many agrometeorological applications including a very good account of the type, accuracy, etc. of the data. The data requirements for agriculture are a requisite to start work on the agrometeorological data bank.

The RA VI Working Group on Agricultural Meteorology considered the problem of agrometeorological data and proposed the possible contents of an agrometeorological data bank (see Appendix 1) prepared by its ad hoc working group. Mr. Sorani (Italy) acted as co-ordinator of this group.

The sub-group considered the ways and means of storage of data used in agricultural meteorology including the establishment of an Agrometeorological Data Bank. Recognizing that meteorological data used in agricultural meteorology are of specific nature and could be exploited in many other fields of applications, the group decided that the establishment of a data bank, including all types of data used by agrometeorologists is a step in the right direction. An agrometeorological data bank or an agrometeorological section of a Meteorological Data Bank should however be limited to the specific elements and data which are not included in the general Meteorological Data Bank.

A case study from the German Democratic Republic is given in Appendix 2. The Meteorological Service runs the united meteorological data bank, while the specific agro-biological data are stored in the data bank of Agricultural Research. This sharing of responsibility between Meteorology and Agriculture enables to reach and maintain a high level and quality of both sets of data (meteorological and agro-biological). The data collected by the agricultural institutions are made fully available to the Meteorological Service, and vice versa.

A quite different approach is seen in the case study from the USSR (Appendix 3). Here a long-series climatological data which are especially valuable for the planning and proper exploitation of natural resources is available. Besides, the Meteorological Service of USSR carries out a number of agro-biological observations and measurements (which in many other countries are within the responsibilities of agricultural authorities). The data are published in the Agrometeorological Annals and are transferred onto the magnetic tapes and computerized.

The building of a central Agrometeorological Data Bank may involve some specific problems. For example, the authority responsible and running the data bank has certainly some monopoly and advantage over other institutions and individuals using the agrometeorological data.

The data bank should therefore have a national character and data for the general public should be made available freely or at a reasonably low price.
Contents of the Agrometeorological Data Bank: Views of the RA-VI Working Group on Agricultural Meteorology.

An agrometeorological data bank should contain meteorological data (see Section A) and agro-biological/soil data (see Section B). The functions of the data bank which should be organized at national, regional and local levels are given in Section C.

Section A - Meteorological Data

A.1 Parameters for description of the meteorological conditions of the atmosphere near the ground
   A.1.1 hourly air temperature
   A.1.2 extreme air temperature
   A.1.3 hourly relative humidity
   A.1.4 extreme humidity
   A.1.5 hourly wind speed/direction and maximum gust
   A.1.6 daily evaporation

A.2 Radiation parameters
   A.2.1 hourly sunshine duration
   A.2.2 hourly global radiation
   A.2.3 hourly net radiation
   A.2.4 hourly cloudiness (amount and type)

Note: Satellite radiative data can be further considered.

A.3 Precipitation parameters
   A.3.1 hourly total, duration, intensity and type of precipitation
   A.3.2 wetness duration

A.4 Parameters for the description of soil climatic conditions
   A.4.1 snow depth
   A.4.2 soil temperatures at 5, 10, 20, 50, 100 cm below the soil
   A.4.3 extremet temperatures at 10 and 50 cm above the soil
   A.4.4 soil moisture (when possible)

A.5 Prognostic data derived from short- and medium-range forecast charts, or post processing methods

Section B - Agro-biological data/soil data

B.1 phenological data (e.g. annual crops, trees, perennial crops)
B.2 agronomical data
B.3 pests and diseases data
B.4 yield data: quantity and quality
E.5 quantity of fertilizers and pesticides and insecticides applied
E.6 field capacity
E.7 water table
E.8 soil conductivity
E.9 pedological data.

Section C - Levels of organization

C.1 At National level, to collect and storage all data listed above and to provide computer programmes for different applications, to disseminate validated and derived data; to disseminate model output data.

C.2 At Regional level, to collect and storage data at regional level; to establish direct access to the National level by using TLC links; to perform special regional applications; to adapt model output to the meteorological and biological conditions in the region; to distribute selected data and programmes for applications by different users.

C.3 At Local level, to collect local data and to adapt regional information to local needs. To prepare special applications programme to be run on P.C.
ANNEX I

A Case Study from the German Democratic Republic

Unified Meteorological Data Store (UMDS) and Computer-based Experimental Meteorological Information System (CEMIS) of the Meteorological Service of the German Democratic Republic

(Prepared by J. Müller, Meteorological Service of the German Democratic Republic)

The use of available meteorological observational information from the Meteorological Service network is a basic necessity in accomplishing tasks related to meteorological research, advice and environment protection. The compilation of the data base and its configuration in usable form through computer processing for comprehensive analysis of observational results is therefore essential. For this reason, the "Unified Meteorological Data Store" (UMDS) was created in the Meteorological Service of the GDR. Neither a specific Agrometeorological Data Store nor an Agrometeorological Data Bank exists in the Meteorological Service of the German Democratic Republic.

Within the framework of the Computer-based Experimental Meteorological Information System (CEMIS), a data bank system will be established in the Meteorological Service of the GDR. The benefits of this system will be derived essentially from its ability to be used in the various individual branches of meteorology and associated fields and in many other specialized domains. UMDS and CEMIS provide the necessary means of ensuring that the growing need for data as a result of Agrometeorological Research and Advisory Work can be covered to a considerable extent.

1. Unified Meteorological Data Store (UMDS)

   The UMDS comprises 5 individual Data Stores (DTS):
   - "Standard Data"
   - "Complementary Programme Data"
   - "Emission Data"
   - "Precipitation Data"
   - "Aerological Data"

   The "Standard Data" (DTS) comprises all standard meteorological ground station data covering measurement and observation of the following parameters:
   - Air temperature
   - Humidity
   - Air pressure
   - Wind
   - Cloud cover
   - Visibility
   - Radiation
   - Precipitation
   - Sunshine
   - Snow cover
   - Ground condition
   - Ground temperature
   - Visual observation of atmospheric phenomena
   - Evaporation
Data for the "suspended particles (dust)", "atmospheric trace gases", "ground moisture", "radioactivity" and "icing", complementary measurement programmes are stored in specific DTSs in the same way as emission data, precipitation data and aerological data. Special documentation exists for all complementary measurement programmes and is kept and constantly updated by the relevant special sections of the Meteorological Service of the GDR. The UMDS contains files valid for the entire store and files assigned to the respective individual data stores.

Common data include:

- UMDS programme library for maintenance, development and utilization of the store;
- Catalogue describing UMDS content, in the form of indices
- Data description tables, which permit UMDS management and facilitate access to the master files.

The individual data stores are generally sub-divided into several file types in which specific data of uniform structure are collected. Several physically-related files (master files) are normally associated with each file type and contain data from several meteorological stations. The content of each file is made up of several parts, or of a single part in specific cases, which in turn can contain several values. Each file has an associated data description table in which computer processing indications are given concerning particularly the file content, the meteorological stations covered by this file and the available time period.

The data description tables provide for data retrieval using programmes from the UMDS programme library. It is possible to incorporate the data description tables of several individual data stores in a file in an organized manner, facilitating simultaneous data search in several individual data stores. All UMDS data are checked using predefined algorithms. Verification criteria include logical association, climatological limit values and also limit values for the change in meteorological parameters with time. Erroneous values will be isolated, corrected or, when this is not acceptable, erased in exceptional cases. The data are stored sequentially in compacted form on magnetic tapes in accordance with a standard principle based on a data description language (Veselov, 1978); After Geithner and Hertrumpf (1989), the data can be selected according to the following parameters:

Meteorological measurement or observational values (element)

- Observing Station and
- Observation period

and can be made available, according to requirements, in the main memory of the computer or on a user-specific data carrier.

2. **Meteorological Data Bank System (CEMIS)**

A Data Bank System comprises a Data Bank Management System and one or more Data Banks. The MIMER Data Bank Management System of UDAC Uppsala,
Sweden, forms the basis of the Meteorological Data Bank System currently being established in the Meteorological Service of the GDR. After Nickschas (1989), the following objectives are to be taken into consideration in the initial stages of CBMIS implementation:

- Mainly formatted data (principally measurements and derived values) are handled in the data bank system. The storage time of observational data in the direct access memory is to be kept to reasonable limits.

- On-line input storage should be provided so that data are available correctly and with minimum loss of time. Input from various data carriers and direct screen input is to be made possible.

- Although data are normally checked prior to input into the data bank system, further checks and corrections have to be made to ensure greater data reliability. A large amount of data is to be condensed after a predetermined time period. Multi-stage data condensing is therefore to be planned, giving monthly, yearly or multi-yearly synopses.

- Access to the Data Bank should be possible from the various specialized branches, i.e. from various points throughout the country. Utilization is possible both for operative purposes (weather service, climate service) and for research and teaching.

- Programmes used nationally should be suitable for adaptation to the data bank, with the possibility of data handling being programmed in high level languages (e.g. Fortran 77). Users want data processing to become more effectively integrated into the work process through interactively defined, executable query methods. The ability to call up pre-formulated, parameterized queries is desirable. The nomenclature should be modelled on familiar terminology. In addition to the MIER command language, users would like to be able to use a software controlled dialogue management system.

Some conditions with which a data bank operating system for meso-meteorological applications should comply are given by Nickschas (1989):

- In view of continuous changes in the meteorological observation systems, the relational model for data banks is to be preferred. The concept is in total opposition to the dynamics of logical data structures.

- The data bank operating system must permit effective multi-user operation. In particular, consistent data reading and analysis must be possible at the same time as data input.

- Meteorological analyses are often conducted in a 6-dimension data environment since any association between the designation of meteorological variables, the three co-ordinates of the location, the precise time and date, and the assignment of values to the variables being analysed implies a six-point relationship.

3. **Dedicated Agrometeorological Data Stores outside the Meteorological Service of the GDR**

A series of data stores exists under the Academy of Agriculture Sciences of the GDR. They are important principally for field experimentation,
plant protection, land improvement, reduction of soil fertility, machine utilization, and for the development of both agrometeorological and agrometeorology-related models and processes, particularly in the context of the research activities of agriculture establishments.

Mention should be made here of:

- "Atmospheric conditions - crop production" (DAWIP)

After Grossman et al. (1976), the inclusion of meteorological parameters in investigations relating to the "soil - water - crop" cause/effect structure, through the development of models for controlling environmental effects (yield programming), is characteristic of the meteorological and phenological information requirement. The "atmospheric conditions - crop production" data store is therefore a specialized data store. It is used in solving the following problems (Grossmann et al., 1976):

- Determination, identification and classification of agricultural locations with a view to their improved exploitation for crop production
- Determination of optimum time periods for agrotechnical operations for the purpose of scheduling dates, work force, equipment and machines;
- Investigation of weather-related effects on yield development, and the development of yield prediction models;
- "Field Characteristics" data store.

The "Field Characteristics" data store holds individual field information covering location factors, plant species and varieties cultivated, arable and crop farming measures undertaking and the yield achieved. These data enable the effect of arable and crop farming measures on the yield to be investigated (Kühn and Stegemann, 1982, Stegemann and Kühn, 1981, Stegemann et al., 1985).

- "Experimentation Results" data store

The "Experimentation Results" data store holds information on experiments in cultivation, fertilizing, tillage, sowing and cultivation times and methods.

- "Plant Protection" data store
- "Soil Data Store"

The soil data store includes information on the proportion of the various types of soils and substrates for all administrative districts of the GDR.

In order to be able to respond correctly to the anticipated sudden increase in the need for cultivation, soil physics and meteorological data in the necessary spatial and time detail, an "information system for complex evaluation of cultivation data" is being created under the Academy for Agricultural Sciences of the GDR, with input from the above data stores.
Bibliography:

GEITHNER, H. u. HERTRUMPF, H.:
Einheitlicher meteorologischer Datenspeicher.

GROSSMANN, K., HELD, J. u. KUNKEL, K.:
Das EDV-Projekt Datenspeicher "Witterung-
Planzenproduktion" (DAWIP). Arch. Acker- u.
Pflanzenbau u. Bodenkld., Berlin 20(1976)5,
S. 333-343.

KUHN, G. u. STEGEMANN, K.:
Untersuchungen zur Erweiterung und Verbesserung
der Nutzungsmöglichkeiten der einheitlichen,
EDV-gerechten Schlagkartei und des Datenspeichers
"Schlagbezogene Kennzahlen" (DASKE) für die
Intensivierung der Getreideproduktion. Diss. B.,

NICKSCHAS, B.:
Aspekte der Datenverwaltung für mesometeorologische
S. 43-45.

STEGEMANN, K. u. KUHN, G.:
Untersuchungen von Produkionsfaktoren bei
Winterrogen durch Häufigkeitsanalysen unter Nutzung
des Datenspeichers "Schlagbezogene Kennzahlen".
Arch. Acker- u. Pflanzenbau u. Bodenkld., Berlin

STEGEMANN, K.; KUHN, G. GARZ, J.:
Probleme der Auswertung von ungeplanten Erhebungs-
daten zur Analyse der Wirksamkeit von Düngungs-
massnahmen, insbesondere der Stickstoffdüngung zu

VESELOV, V.M.:
Jazyk opisaniâ gidrometeorologiceskîh dannyh.
ANNEX II

A CASE STUDY FROM THE USSR

(Agrometeorological Data Bank)

by

A.N. POLEVY

(The English translation provided by the author is reproduced without any editing)
ON AGROMETEOROLOGICAL DATA BANK

by A.N. Polevoy,

Working Group on Agricultural Meteorology (R.A. VI)

The main approach to more effective use of the large bulk of versatile hydrometeorological information accumulated during many years is to create the technique, using computers for data processing and storing in storage media meeting the demand of long preservation at multiple usage.

To create the informational base of Historical Reference Data Bank (HRDB) "Agrometeorology" the agrometeorological annuals (AMA) were used, which embraced a considerable length of time. The technical and economic grounds for such a choice were as follows:

1) Information in AMA meets most closely general requirements to the composition of data base;

2) The initial data in AMA have the required quality.

Discussing the essence of the former consideration it should be noted that information contained in Data Bank, can be viewed upon as a set of interrelated, accumulated and conjugated data with such a minimum excess, that allows one at adequate organization and methodology to use it optimally in versatile ways. The bulk of tables in the annuals contain data on stages of development and state of crops and perennials during the period of their vegetation, data on cultural practices, elements of productivity, yield structure, soil moisture regime, conditions of overwintering, grazing and other data generalized according to certain principles, i.e. tailor-made for the convenience of the user.
The latter consideration is determined by the composition of annuals, where observational data from agrometeorological and meteorological stations and posts for regions, territories, etc. are included after multiple technical and critical check. The block diagram for the creation of data base for Historical Reference Data Bank "Agrometeorology" is presented in Fig.1.

The whole technological complex of activity, covered by several departments of Hydrometeorological Service of the USSR, is carried out under the methodological control of the head-quarters agrometeorological institute. Let us discuss the stages of this activity.

To solve most agrometeorological tasks and to serve the user, it is enough to provide not the whole bulk of accumulated initial information, but a certain part of it, properly checked (technically and critically) and processed, i.e. generalized according to interstage periods, other time intervals or otherwise. As it was mentioned above the data from agrometeorological annuals served for it as a base.

Unfortunately data contained in the annuals have a limited access to users, as its retrieval is time- and labour-consuming. With the aim to automatize data processing and to accumulate and modify the information of the data bank on agrometeorology under development the preparatory work was carried out to prepare data from AMA (for the previous years) for recording on storage media with the help of Magnetic Tape Data Handling Device (MTDHD) of United Series(US)-9002. Here we meet certain difficulties. On one hand, the prepared data are to be presented in such a form, that their entrance into district computer centers should be simple enough and within reach of the operator, on the other hand the formalization level for data recorded on the
Fig.1. Historical Reference Data Bank "Agrometeorology" - Block diagram of data fund creation
magnetic tape, is to provide the possibility to treat automatically information by computers and to transfer it to the user.

The analysis of annuals has shown that practically all of them contain tables, that differ considerably from standard lay-out sheets of AMA. It can be explained by particular information for certain regions and by many other reasons.

Taking this into account, the task to formalize the information taken from annuals, can be solved in two ways: either by expanding the standard set of lay-out sheets for tables, or by describing every real table deviation from standard lay-out sheet according to the developed rules. With this in mind, some compromising variant was used, namely:

- the set of standards lay-out sheets for tables was expanded;

- the special language was developed, that described in the formalized way the deviation of real tables from the expanded set of standard lay-out sheets of tables;

- information from annuals is to be recorded on magnetic tapes in the formalized shape, using for this purpose MTDHD USC - 9002.

To formalize the information of annuals and difference of real tables from standard lay-out sheets, the rules are developed for entry lines of information into magnetic tape (MT) of MTDHD US 9002, concerning titles within tables, notes and such notions as Table Describing Line, Annex to Table Describing Line, Annual Beginning and Annual End, added specially for that purpose.
These constructions along with the rules of annual data recording served as the basis to solve the problem of information formalization in the agrometeorological annuals with the goal to enter it into a storage medium. This gave the real possibility to solve the problem of automatization of ANN data processing using computers.

Preparation of annuals for recording is carried out by specialists from agrometeorological observatories. It takes usually 7-8 working days for an agrometeorologist to prepare an average ANN for recording on a storage medium and after that the prepared annuals are into MTDHD-9002.

The next stage of data bank creation is to check and correct the entered information. The task is to check the correctness of entry on the magnetic tape and to find appropriate auxiliary features in different types of recording. There are several ways to check the data recorded on storage media. One of the most labour consuming but widely used method is one of print out comparison with the original. The structure of data recording on magnetic tapes differs from the presentation in annuals: in the latter data are tabulated, while in the former one information is arranged sequentially (line after line) and divided into blocks of 80 signs. The closer data arrangement in print out to the tables in annuals, the higher proof and speed of checking. Some types of tables that contain textual information, gaps in the abridged notation and dimensional representation are not easy to present in the print out in the form of the original. That is why such data may be presented to the print out in the way they were recorded on the magnetic tape.
Thus, depending on the complexity of tables the check of information can be carried out on print-outs either in the form of tables or in the form of magnetic type presentation.

Information check by the format of data recording on magnetic tape is based on the comparison of lines of the real table in the annual with the lines of print out. Using such approach it is easy to locate surplus blocks but other mistakes are not clearly seen and can be identified only by more strict comparison. This format can be recommended to check the data incorporating large bulks of text and abridged notation.

Data check using prints in the format of tables from annuals allows one to check not only lines, but columns too, which leads to higher speed and better reliability of proof-reading. This format is convenient only in a case where abridged notations are not used and textual information is uniformal.

Errors of information recording on magnetic tape can be corrected either by MTDHD US 90002, or by programming at the moment of data file formation on the conventional magnetic tapes of US computer type. Correction by MTDHD 9002 is carried out according to the rules, given in the engineering specifications of this device. This method allows one to correct all types of mistakes, but inserting missing blocks, to correct the latter mistake the programming method is used. Data correction by programming is made at file formation on magnetic tape USG. Initial set of data, intended for correction, goes to the first file of magnetic tape of MTDHD, while corrector (instructive part of the correction) belongs to the second file of magnetic tape MTDHD. Corrector is a formalized set of rules, including type, place and way of mistake correction (substitution, insertion or
withdrawal) within a block or for a solid block.

Information organization on standard magnetic tapes depends on the volume of information for entry, prompt retrieval of the required data and a number of requirements specified by operating conditions of US computers, and in particular on the requirements of the operational system. An agrometeorological annual can contain from 0.1G up to 3.0 mbyte of information. That is why data from a separate annual should be presented on magnetic tape of USC type as a separate file, i.e. file of data. For the purpose of prompt archive processing, a file of data description is formed before the file of data. The file of data description consists of the list of lines describing tables in annuals. Such a line is composed of the number of standard layout sheets of tables, code of the crop/s and identifiers of different departures of the real tables from standard layout.

The data file is composed of the information of a separate annual and contains the following:

1. Identification of annual's beginning;

2. Data of annual's tables, including the line of table description, annex to the line of description, heads within the table, essence of the tables arranged in lines and notes at the end of the table;

3. Indication of annual's end.

The organizational structure of the data fund is to be divided into three levels of data presentation, i.e. into

a) level of subject-matter,

b) logical level,

c) physical level.
This approach allows one to couple the sense of the object with the mathematical description of the structure, with the choice of ways and forms of data keeping on the storage media, and with algorithm development for the applied programs to use the fund of data.

The subject-matter level of the data structure is the concrete object of application (primary structure of the object, its subject-matter, etc.) which constitutes the informational data base. This level allows specialists in different fields to communicate at any stage of data bank creation and functioning. The object of application in our case is, as mentioned above, an agrometeorological annual, the content of which is the information received as a result of agrometeorological observations by a net of stations and posts during a year in separate regions.

At designing a concrete base of data, the choice of logical structure is very important as it is to match the subject-matter and to be realized effectively on the available storage media in the form of a physical structure. The problem solution algorithm lays in building of the subject-matter model of data and in converting this model into such a form which reflects the logical structure of data. Nowadays the logical structure is divided into three basic models: the net, the hierarchical and relational ones.

Analysing the fund of data in an agrometeorological annuals, one can easily see that it has a tree (or hierarchical) structure (Fig.2). Such a structure of the historical agrometeorological information was being developed during a certain period of time and is determined by the necessity to generalize data by different factors:
Fig. 2. Logical structure of AMA data fund
- natural-climatic conditions of regions;
- temporal presentation (year);
- object of observation (meteorological conditions, soil moisture, features of crop development, of cultural practice, yield characteristics, etc.);
- coordinates of observations (stations and posts).

Under physical organization of data we understand their structure at storage media, which can be described as a result of correspondence of data structural elements to the physical units of memory space, i.e. files, blocks, records and bytes. While developing informational base one of the main demands to be met is the choice of optimum physical characteristics of data sets. The choice physical organizing is determined by a number of factors, bound up with the type of a storage medium, frequency of file use, storing regime and body of information.

A prerequisite for any type of data management and access is the language means for the description of logical and physical data structure and communication with the data base. The AMA data fund is an intermediate organization of data, that is why such a means of data base compilation as the language of data description (LDD) and the language of data manipulation (LDMM) which are indispensable attributes in the making of DB, are not used at this stage. As a language means of AMA, a systematized vocabulary of agrometeorological parameters is used to describe, on a standard basis, the parameters of one type, their completeness and the access to the information base.

The systematized vocabulary of agrometeorological data is based on the contents of captions of standard lay-outs of the AMA
tables. Each table caption is a list of parameter names divided into different groups. Some parameter names are repeated in different tables. The most optimal vocabulary structure might be made using the following rules:

1) Every parameter (the name of a physical unit, characteristic of conditions, etc.) is repeated in the vocabulary only once.

2) The position of the parameter in the vocabulary depends on its repeatability in the AMA tables.

3) The entire vocabulary is divided into groups on the basis of information content (meteorological conditions, crop species, etc.).

Such a vocabulary structure enables one to avoid the duplication of the parameters and to economize the capacity of data carrier storage. However, the use of this vocabulary involves a formalized description of the captions of all standard tables. This formalized description must adequately reflect the entire structure of the table captions (the order of the columns and the extent of their generalization by levels). Fig. 3 shows the table lay-out structure with a two-level grouping of the parameters. In the total list of the lay-outs there are tables with as many as four levels of grouping. Since actual AMA tables are mostly different from the standard lay-outs, the access to the elements is possible only after the table correction is made to their standard lay-out (checking additions, divisions, deletions, changes and removals of column positions). The use of the formalized description of the lay-outs and vocabulary based on the above rules do not allow a rapid selection of the lower level elements.
Table 16.1. Cultural practices and crop yields on an observational plot under hemp

<table>
<thead>
<tr>
<th>Station No. and name</th>
<th>Plot No.</th>
<th>Location</th>
<th>Soil type</th>
<th>Predecessor</th>
<th>Frosowing treatment of soil</th>
<th>Sowing rates &amp; type</th>
<th>Fertilization</th>
<th>Cultural operations</th>
<th>Final yield, q/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>type</td>
<td></td>
<td></td>
<td>date, weight, q/ha</td>
<td>type</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>date</td>
<td></td>
<td></td>
<td>t/ha</td>
<td>date</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>9</td>
<td>10</td>
</tr>
</tbody>
</table>

1. Station No. and name
2. Observational plot No.
3. Location
4. Soil type
5. Predecessor
6. Type of prosowing treatment of soil
7. Date of prosowing treatment of soil
8. Sowing rates and type (kg/ha)
9. Frosowing treatment of seeds
10. Application date and fertilizer name
11. Fertilizer weight, q/ha (t/ha)
12. Type of cultural operation
13. Date of cultural operation
14. Final yield, q/ha

Fig. 3. The lay-out of Table 16.1 and a section of the systematized vocabulary compiled on the basis of the given lay-out
ments in the structural information tree (Fig. 2). Thus the correction method and the principle of the access to the table elements determined a somewhat different approach to the building of a systematized vocabulary. Its essence is in the fact that the position of the parameters within the vocabulary is in strict accordance with their succession in the standard table lay-outs. This approach enabled one to get rid of the formalized description of the standard table lay-outs and, respectively, of their decoding. Arranging the table captions at one level enabled a simpler programming solution of the access and correction of data. The data correction in this case is the listing of the parameters according to the actual AMO table on the basis of the parameter list of the standard table lay-out, its description line and annex to the description line. This table correction is made each time during the user request.

Several access levels can be distinguished on the basis of the principles of the AMO data bank management (Fig. 2):

1) At the file level (annual). This access is made using the operational system, for compiling data arrays, mainly on data carriers. The AMO alphanumeric printout is small.

2) At the table level. At this level the access is made through key elements including the attribute of table beginning, table number and in some cases the crop code. In practice the key element is a part of the table description line situated at the data carrier before the table contents.

3) At the line level. The access to the table line is made through the key elements of the corresponding table and the line. As a key element, the station number and name is used.

4) The access to the table name elements (parameters).
There are two options of the access to the elements: the access to the elements of a separate line and the access to the table columns. Due to technological reasons of entering the AMA data on the carrier the tabble elements in the line are not arranged either positionally or on the key basis, thus the access is difficult. Under the accepted data fund structure the line element or a column can be sought only in accordance with the parameter number in the systematized table vocabulary.

The data base of the NRDB "Agrometeorology" is unique due to the miscellaneousness of agrometeorological data as compared with other types of hydrometeorological information, and to the complexity of their representation in basic data. AMA is specific in the main characteristics being presented as tables, with the tables being composed on the basis of such data presentation which is convenient for the analysis of crop growth conditions in a growing season of a particular year. That is why the tabulated data include,(in addition to basic data, the calculated values of complex characteristics,required.

One of the main functions of the automated information systems is regular services including the capabilities for the solution of the following problems:

- calculation of potential climatic resources at different areal scales;

- probability agroclimatic forecasts for a five-year term and for longer term planning of agricultural strategy;

- forecasts of agrometeorological situations on the basis of analogous observation of the growing season conditions;

- calculation of probability schemes of plant development
conditions when anomalous weather conditions arise;

- request-response on the basis of the data bulk used most often.

Three levels can be distinguished in the general structure of the DB system. Till now, the first one has been discussed, the top level at which the central DB "Agrometeorology" is situated and historical agrometeorological information accumulated by the network is stored. It is assumed that the second (regional) level stores and handles, on the user request, similar data for larger areas, e.g., for economic regions.

To the third, local level, special-purpose DB corresponds, which stores the data of agrometeorological observations for selected regions or districts. Specific implementations of these can be very different. In future, to satisfy numerous and different user requests, the information supplied by the local DB must have the required areal and temporal recognition. The main task of developments at this level is the achievement of data independence, i.e., the possibility of changing the storage structure or access method without changing the routines of data processing. The general methodology of making the system of historical reference data banks implies that main functions of processing different types of hydrometeorological data are executed by the standard means of the Data Management System of the Automated Imitation System of Historical Data Processing (DHIS of AISIDR). However, such specific features of agrometeorological data as episodic acquisition and versatility of characteristics require the development of special-purpose routines. The latter on the one hand must better meet the user requirements, and on the other meet the requirements of research efforts in agrometeorology.
and related fields of knowledge. Such developments may be very promising; this demands not only that the available routines of HRDB be essentially developed, but also that it be developed at a qualitatively higher stage, by designing the second version of the routine package enabling the use of the DB "Agrometeorology".

Indispensable sections of the perspective software for HRDB "Agrometeorology" are:
- the reference data base system;
- the system of structural modifications of archive files (truncation and smoothing at the areal-temporal scale, account for the annual run, smoothing of process);
- the means for the assessment of information quality;
- a service system (the means of file transformation and data visualization).

Agrometeorological data characteristics can be taken into account during the data manipulation and formalized use of the notions "growing season", "crop year", "agroclimatic zone", "physiographic soil property", etc. The HRDB "Agrometeorology" software and data base are believed to be designed and developed as expanding systems.

The most important future-oriented problem is the development of software for the design and use of the above-mentioned specialized DB. The assumption is that the entire automated data system can be based on the direct-access facilities and can be controlled by the dialogue system of data management. In this way one can solve the problem of operational access to data, to minimize the time of processing the user requests. Ultimately, the problem is to divide the requests into two flows: operational one, handled on the basis of
Fig. 4. Agrometeorological data services with the use of Operational and Historical Reference Data Banks at a regional level.
special-purpose DB within an automated information system, and a stored flow handled by the facilities of the expanded DLIS of AISNDF on predetermined dates.

Perspective problems arising at the stage of the use of HRDB "Agrometeorology" may be solved on the basis of the general scheme of agrometeorological data services shown in Fig. 4.

In nearest future HRDB "Agrometeorology" must be set up and used at the second, regional level. Without going into details of the composition and functional structure of the Operational Data Bank (ODB), one must emphasize the urgent need to rapidly implement in practice the concept of the HRDB system development at a regional level. When at this level effective means of methodology and software are used, prerequisites may be formed for a realistic solution of the problems of servicing the middle- and lower-level users, on a real-time basis, using conventional computers. The experience gained shows that it is only at this level that high quality of basic data can be assured, which can be used for calculations, generalization and incorporation in the regional HRBD. This approach results in an acceptable user regime in HRDB "Agrometeorology". The users, taking into account the need to acquire the historical data operationally, may apply not only to the highest-level HRDB, but also send requests at a regional level.

REFERENCES


PART IV-A, INFLUENCE DU TEMPS ET DU CLIMAT SUR LA QUALITÉ DES RECOLTES

(par M. Denis PAYEN, Météorologie Nationale, France)
INFLUENCE DU TEMPS ET DU CLIMAT
SUR LA QUALITÉ DES RECOLTES

L'agriculture européenne, et plus généralement celle des pays développés, est confrontée à des problèmes spécifiques liés à la situation socio-économique et aux conditions d'environnement. Le volume de la production, s'il reste un objectif important à atteindre, tend à n'être plus le problème prioritaire, par rapport à ceux des coûts de production et ceux de la qualité des récoltes. Dans un contexte d'application de quotas de production ou de déprise des terres, un éclairage nouveau est donné aux agrométéorologues pour examiner les services et informations qu'ils doivent fournir aux agriculteurs. Il ne s'agit plus d'aider à produire plus, mais à produire mieux et à maîtriser les coûts et la qualité des produits agricoles. La question de la qualité des récoltes comporte différents aspects : qualité nutritionnelle, qualité technologique, qualité sanitaire ainsi qu'un aspect plus subjectif, qu'on pourrait appeler qualité gustative. Sous ces différents aspects, le temps et le climat jouent un rôle extrêmement important, dont des exemples seront fournis dans ce qui suit.

QUALITÉ TECHNOLOGIQUE

La qualité technologique s'entend comme l'aptitude du produit agricole récolté à être utilisé pour fabriquer des produits agro-alimentaires ou de transformation.

L'exemple qui vient immédiatement en tête concerne le blé. Le potentiel de production de cette céréale a considérablement augmenté, en moyenne de plus d'un quintal par hectare et par an en France, en même temps que baissait notamment le taux de protéine. Certains blés avec des potentiels supérieurs à 100 g/ha sont inaptes à la fabrication du pain, ce ne sont plus que des blés fourragers. Une étude sur la qualité boulangère des blés a été conduite, notamment par l'Office National Interprofessionnel des Céréales et l'Institut Technique des Céréales et Fourrages. Les observations montrent que, certes, la qualité boulangère des blés dépend principalement de la variété et des pratiques culturales, en particulier la maîtrise de la fertilisation, mais également du climat. Celui-ci exerce son influence par exemple sur la teneur en protéine. Il peut également par ses manifestations extrêmes conduire à une dégradation de la qualité de la récolte. Ainsi qu'il a été noté en juillet 1987 où les conditions extrêmement pluvieuses et humides régnant d'ailleurs depuis mai dans la majeure partie de la France, ont même conduit à des germinations sur pied.
La qualité du maïs est également dépendante des conditions météorologiques. Par exemple, le potentiel germinatif du maïs-ensemence peut être entamé par des légères gelées en automne avant la récolte. Ces légères gelées, repérées par des températures minimales relevées sous abri à peine inférieures à 0°C, ne sont en général pas préjudiciables au maïs-grain, au contraire, si le froid survient progressivement et comme il est souvent associé à des masses d'air sec, il exerce même une influence positive par dessiccation sur l'humidité du grain. Il convient donc d'être attentif aux conditions de température au moment de la récolte du maïs-ensemence.

Un autre aspect concerne la qualité amidonnière du maïs. Celle-ci est étroitement dépendante de la variété de maïs cultivé, en particulier du type de grain (denté, corné, corné-denté), mais aussi du climat. Souvent cette influence se note certaines années défavorables où les industriels observent dans les unités de production d'amidon, des rendements particulièrement pauvres. C'est ainsi qu'une société multinationale de production d'amidon s'est adressée au Service Météorologique Français afin d'obtenir les informations agrométéorologiques nécessaires à leur politique d'achats de maïs. Des données décennales de hauteurs des précipitations et de sommes de températures supérieures à 6°C ont été envoyées par téléx en temps quasi-réel au siège de cette société d'avril à octobre, où un système (confidentiel) d'analyse permettait d'orienter les achats dans telle ou telle région de France où le climat s'était révélé favorable.

Il faut aussi citer l'influence des températures élevées sur la qualité de l'orge de brasserie. Il est généralement constaté qu'un taux de protéines supérieur à 11.5% dans l'orge entraîne des problèmes dans la fabrication de la bière qui apparaît trouble. Il a été observé, en particulier dans le Loiret au cours de la deuxième moitié du mois de juin 1986 que des températures maximales supérieures à 32°C durant 3 jours avaient porté les taux de protéines dans l'orge à des valeurs de 13 à 14%, ce qui a considérablement obéré la qualité de l'orge de brasserie.

La qualité de la fibre de lin est également dépendante des conditions de températures. Une croissance lente et régulière de la plante, liée à un régime thermique tempéré, est favorable à la qualité des fibres. C'est ainsi que les régions côtières de l'Europe du Nord apparaissent privilégiées et sont des zones de production traditionnelle, tandis que le lin pour l'huiile ou les semences est également cultivé dans les régions plus méridionales.

Dans le même registre de la qualité technologique, il faut ajouter la surveillance des conditions de maturation, et la planification de la récolte de petits pois, de haricots verts, de maïs doux ou de tomates. Pour les trois premières cultures, la récolte doit se faire à un stade très précis afin d'obtenir une qualité requise (haricots ou pois extra-fins, fins, mi-fins : le maïs doux doit être récolté au stade grain-l'aïtox). Il est également nécessaire d'échelonner les récoltes (y compris pour la tomate) pour ne pas saturer les conserveries. Pour cela, le calendrier des semis doit être très attentivement déterminé et le développement des cultures doit être également surveillé. La méthodologie consiste à effectuer une analyse fréquentielle des sommes des températures de façon à établir un calendrier de semis optimum, et ensuite d'effectuer un suivi climatique précis avec prévision de stades phénologiques de façon à récolter le produit agricole au stade optimum de qualité, donc ce meilleur valeur commerciale. C'est ainsi que dans le Sud-Ouest de la France, une étude a été conduite dans la région d'Agen (Lot-et-Garonne) de façon à établir des calendriers de semis de maïs doux en fonction du climat, des variétés et de la situation des parcelles cultivées.
QUALITÉ SANITAIRE

Il faut entendre par qualité sanitaire, l'ensemble des caractéristiques du produit agricole qui garantissent sa conservation, la pérennisation de ses qualités technologiques et la santé du consommateur. Dans ce domaine, se posent les problèmes liés aux maladies et aux ravageurs des cultures, aux résidus chimiques dans les produits alimentaires dérivés, aux conditions de transport et de stockage, et éventuellement à l'influence de la pollution. L'influence du temps et du climat dans ce domaine apparaît évident (1). Un exemple le démontre aisément.

Il s'agit des méthodes de contrôle de la tavelure du pommier. Cette maladie due au champignon Venturia inaequalis provoque des dégâts sur les fruits qui réduisent à rien leur valeur commerciale. Une pomme même très légèrement tavelée ne se vend pas : le seuil de tolérance de la maladie est donc zéro, et il est impératif de la contrôler. Des parasites chimiques existent, les fongicides, qui ont souvent été utilisées dans des systèmes de traitements systémiques préventifs.

En France, selon la climatologie régionale le nombre moyen de traitements antitavelure nécessaires de mars à août peut varier de 8 dans la vallée du Rhône ou en Provence, à 15 dans le Val de Loire et le Sud-Ouest. Il est évident que ces nombres élevés rendent le contrôle de la maladie coûteux, et peuvent entraîner des problèmes tels que les résidus chimiques sur les fruits, les risques d'induction de souches résistantes de champignon, la pollution de l'air, de la terre et de l'eau. Sur un strict plan de la qualité, il est indispensable de limiter les résidus et d'éviter les souches résistantes ; par ailleurs l'impératif de maîtrise des coûts de production a conduit à l'utilisation d'un système de contrôle par une stratégie de traitements raisonnés, qui demande un suivi climatique très précis (2).

En effet, les risques de contaminations dépendent de la sensibilité variétale, de la quantité d'inoculum provenant de l'année précédente, et surtout du climat. L'infection nécessite des conditions définies par la température et la durée d'humectation du feuillage. Il est possible d'apprécier les conditions propices à l'attaque par le champignon à l'aide des courbes de Mills (3) (graphique 1). Pour cela sont implantées dans les vergers des réseaux tavelure, avec des stations hygrothermométriques, mesurant de plus la durée d'humectation à l'aide de l'humectographe kit-INRA (4), ainsi que les hauteurs des précipitations. Les données sont relevées par les arboriculteurs, centralisées grâce à un ensemble de répondreurs téléphoniques, et traitées pour établir la gravité du risque d'infection à l'aide des courbes de Mills et d'un système de correction fondé sur l'humidité relative pendant la période sèche séparant deux périodes d'humectation.

Par ce système d'information, il est possible de ne traiter que lorsque les risques d'infection sont réels, à l'aide de fongicides curatifs. La surveillance des précipitations lessivantes est nécessaire. Au cours d'une expérience de trois années en Val de Loire, il a été clairement démontré que la stratégie raisonnée permettait une économie de 30 % en moyenne des traitements. Ces chiffres se retrouvant globalement pour d'autres régions en France.
L'intérêt du système est double sur le plan de la qualité, puisqu'il permet un bon contrôle de la maladie et de réduire les résidus chimiques. Il est ainsi prouvé que la surveillance du climat peut contribuer à améliorer la qualité sanitaire des pommes.

Un autre exemple de l'influence des conditions météorologiques sur la qualité sanitaire est relatif à la conservation des pommes de terre (5). Une conservation de longue durée de ce produit demande que soient assurées des conditions microclimatiques particulières, avec un optimum de température compris entre 3 et 10°C, une ventilation modérée (0 à 0,03 m/s) destinée à maîtriser l'humidité relative sans toutefois entraîner des pertes d'eau par évaporation. Par ailleurs, avant même le stockage, il convient de s'assurer de bonnes conditions au moment de la récolte, c'est-à-dire de l'absence de blessures ou de maladies, par exemple de mildiou qu'il est possible de contrôler également par des méthodes de traitements raisonnés.
LE CAS DE LA BETTERAVE SUCRÉE

Des études ont été conduites en France, sous la direction de N. Gerbier (6), afin de mettre au point une méthode opérationnelle de prévision des rendements de la betterave sucrière, à l'échelle d'un département, en fonction de critères climatiques.

Pour cela ont été utilisées des modèles empirico-statistiques (7) utilisant les techniques classiques de corrélations et de régressions multiples. Une analyse statistique a permis de confronter des variables biologiques telles que le taux de saccharose, avec une gamme de paramètres météorologiques calculés sur des périodes pluripluviométriques glissantes, tout au long du cycle de la betterave (8).

Une présentation de résultats figure sur le graphique 2, où apparaissent des facteurs météorologiques favorables et défavorables au taux de saccharose des cultures de betterave du département de Seine-et-Marne. Par exemple, il existe une corrélation négative \( R = -0.778 \) entre le taux de sucre et les hauteurs des précipitations du 6 septembre au 15 octobre. De façon plus générale, il est mis en évidence un effet positif en été et début d'automne, des facteurs radiatifs et thermiques, tels que l'évapotranspiration potentielle (ETP), la durée d'insolation (INSO), le rayonnement global (RG), l'amplitude de température (TX-TN). Il faut noter, outre l'effet négatif des précipitations en mai-juin et septembre-octobre, un effet défavorable des basses températures au printemps, par exemple les sommes des températures minimales inférieures à 5°C (TN < 5) du 6 au 30 avril qui sont corrélées négativement \( R = -0.573 \) avec le taux de saccharose.

L'influence des facteurs météorologiques sur le rendement (en poids) de la betterave sucrière est résumée sur le graphique 3. Il y apparaît que les précipitations excédentaires sont défavorables en mars et début avril, au moment de la préparation des sols et des semis. En été, la sécheresse est nuisible à un bon rendement, bien qu'il puisse y avoir un certain rattrapage en septembre si les pluies sont supérieures à la normale. Pour le département de l'Aisne, les coefficients de corrélation les plus élevés se rapportent au facteur eau, en particulier au bilan hydrique potentiel (pluie-ETP). Pour la Marne, la période d'influence est même plus longue (juin-juillet). En Seine-et-Marne, les facteurs durée d'insolation et amplitude thermique en été ont un effet très défavorable sur le rendement en poids.

Il apparaît donc une opposition nette de l'influence des facteurs climatiques en été. Le facteur eau est favorable au poids de la betterave sucrière, mais pas à sa qualité, mesurée par le taux de saccharose. Les facteurs héliothermiques sont, quant à eux, favorables à la qualité, mais défavorables au poids.

LE CAS DU CHAMPAGNE

Les conditions météorologiques jouent un rôle déterminant sur la croissance et le développement de la vigne, ainsi que sur la production et la qualité du raisin. En liaison avec l'influence du climat, les caractéristiques des cépages, les conditions pédologiques, l'intervention de l'homme, participent à la constitution d'un équilibre favorable à la culture de la vigne.
En Champagne, où sont présents les trois cépages : Pinot Meunier, Pinot Noir et Chardonnay, l'influence des facteurs climatiques sur la date de vendange, la production, le degré d'alcool et le taux d'acidité, a été étudiée (9).

La méthodologie utilisée pour conduire ces études est semblable à celle déjà décrite dans le chapitre précédent, à savoir des modèles empirico-statistiques. Les données agronomiques, fournies par le Groupement Champenois d'Exploitation Viticole, ont été confrontées aux paramètres climatiques relevés à la station météorologique de Reims. C'est ainsi que, pour ce qui concerne la qualité, ont été examinés le degré alcoolique et le taux d'acidité de l'année i, en regard des conditions météorologiques ayant régné l'année i et l'année i - 1, puisque le cycle végétatif est de deux années.

Les graphiques 4 et 5 rassemblent les résultats concernant le cépage Pinot Meunier, où figure dans chaque colonne le paramètre considéré, la période durant laquelle il exerce son influence, et le coefficient de corrélation associé. Par exemple le degré d'alcool est corrélé positivement avec la durée d'insolation cumulée du 21 avril au 20 septembre avec un coefficient de 0.724.

L'examen de ces graphiques, de même que celui des graphiques relatifs à Pinot Noir et Chardonnay, fait ressortir les effets suivants des paramètres météorologiques sur la qualité du vin de Champagne, paramètres qui sont les précipitations, les durées d'insolation, les températures moyennes, les amplitudes des températures, le rayonnement global, l'évapotranspiration potentielle, les sommes des températures moyennes supérieures à 4°C, les sommes des températures maximales supérieures à 10 et 15°C.

Deux périodes privilégiées ressortent nettement de l'observation des tableaux de corrélation avec le degré alcoolique : d'une part l'été et une partie de l'automne de l'année i - 1 (jusqu'à la mi-novembre) et, d'autre part, la période allant du printemps jusqu'aux vendanges de l'année i. Les trois derniers mois du cycle constituent une période particulièrement sensible, pour les trois cépages, en ce qui concerne les hautes de précipitations (fin juin à début octobre) et les sommes de températures maximales supérieures à 10°C (fin avril à octobre). Ainsi, il semble bien que la qualité (degré d'alcool) de la récolte soit intimement liée aux conditions climatiques survenant dans la dernière partie du cycle de la vigne. Cette constatation se retrouve, dans une moindre mesure (avec un décalage d'un mois en avance pour les pluies) sur les résultats obtenus en corrélation avec le taux d'acidité.

Pour chacun des deux critères de qualité étudiés, les réponses se ressemblent d'un cépage à un autre avec les nuances de détail en particulier quant à l'importance relative des incidences de tel ou tel critère climatique.
Un fait particulièrement remarquable est le poids important et radicalement opposé, quand on passe de la première année à la seconde année, des pluies - mais aussi de l'insolation et de l'amplitude de température - observé approximativement à la même époque de l'année (de l'été au début de l'automne). Cette remarque est surtout valable en ce qui concerne l'alcool. Ainsi un excès de pluies - par rapport à la normale - se révèle favorable à la constitution d'un degré alcoolique élevé s'il survient au cours de l'été de la première année, alors qu'il est particulièrement néfaste s'il est enregistré durant l'été de l'année de la vendange. Le temps qu'il fait au cours de l'année s'il influe prioritairement sur la qualité de la récolte immédiate, détermine également dans une certaine mesure celle de la récolte de l'année suivante qu'il oriente vers une tendance opposée (les coefficients de corrélation sont de signe contraire d'une année sur l'autre).

Un autre point à souligner est la différence sensible de réaction relevée entre les deux critères de qualité, surtout au niveau des périodes d'influence, les valeurs des coefficients de corrélation étant comparables et leur signe naturellement opposé pour une époque donnée. Cette observation confirme le bien-fondé du traitement séparé du degré alcoolique et du taux d'acidité.

La dépendance des paramètres climatiques entre eux est retrouvée par l'intermédiaire des corrélations. Ainsi, par exemple, le fait que, vis-à-vis de l'alcool, les pluies ont un impact positif au cours de l'été de l'année - 1 est cohérent avec l'observation du poids défavorable de l'insolation ou des amplitudes de températures élevées à la même époque. Mais cette pluralité de résultats permet de mettre en relief le critère déterminant qui est en l'occurrence l'amplitude de température ou l'insolation suivant le cépage.
### Graphique 2 : Influence des facteurs météorologiques sur le taux de saccharose de la betterave sucrière en Seine-et-Marne

<table>
<thead>
<tr>
<th></th>
<th>PR</th>
<th>ETP</th>
<th>INSO</th>
<th>RG</th>
<th>TX-TN</th>
<th>TN S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Janv</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fév</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-533</td>
<td></td>
</tr>
<tr>
<td>Mars</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-533</td>
<td></td>
</tr>
<tr>
<td>Avril</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-493</td>
<td>-573</td>
</tr>
<tr>
<td>Mai</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-499</td>
<td>548</td>
</tr>
<tr>
<td>Juin</td>
<td></td>
<td>-495</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Juil</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>537</td>
</tr>
<tr>
<td>Août</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sept</td>
<td></td>
<td></td>
<td>538</td>
<td></td>
<td>522</td>
<td>501</td>
</tr>
<tr>
<td>Oct</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>584</td>
<td>584</td>
</tr>
</tbody>
</table>
Graphique 3 : INFLUENCES DES FACTEURS MÉTÉOROLOGIQUES SUR LA BETTERAVE SUCRIÈRE DANS CINQ DéPARTEMENTS FRANÇAIS.
<table>
<thead>
<tr>
<th>CHAMPAGNE - PINOT MEUNIER - ACIDITÉ</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
REFERENCES BIBLIOGRAPHIQUES

1) PAYEN D. et RAPILLY F., 1989 - L'agrométéorologie et les maladies des plantes. La Météorologie, 6 (15), 24-29.


PART IV - B: INFORMATION ON THE STUDY OF WEATHER AND CLIMATE IMPACTS ON THE QUALITY OF GRAIN CROPS

(DISCUSSION DURING WG MEETING - AN EXTRACT).
Grain productivity is the key problem in agriculture. Forecasts of grain quantity and quality play an important role, as means of controlling the production, procurement and distribution of agricultural produce. The basic indices of grain quality are protein and gluten content, as they are linked to the basic process, milling and baking characteristics of the grain and to its market value. On the world market, the price of grain is basically in direct proportion to its protein content.

Proteins are the most valuable part of the edible material contained in grain. It is no coincidence that the Greek roots of the word "protein" mean "primary" or "chief". Proteins are mainly made up of amino acids, of which eight are indispensable; they are vital to the life processes or every living creature. However, these amino acids are not synthesized by either the human or the animal organisms, and can only be obtained from vegetable foodstuffs, including grain products. It is also no coincidence that the problem of increasing the protein content of grains has been called the "problem of the age". More than half the world's population suffers from "protein starvation", which consists not so much in not having enough food but in having food that is unbalanced, inferior and low in protein.

The protein content of grain and the quality of its gluten are inherited, and are largely dependent on the plant variety. However, one should not take a high protein and gluten content and assume that it is the level that is characteristic for the type, as they display great variability, which also includes variability over a geographical cross-section and depending on climate, soil characteristics and agriculture techniques. On the whole, the effects of climate far outweigh the effects of agriculture techniques.

In finding a solution to the protein problem, science has at its disposal quite an extensive body of research, devoted to studying how the amount of protein and gluten in the grain varies depending on the characteristics of the variety, on agricultural techniques and on soil, climate and weather conditions. As we said, the protein content of grain and the quality of its gluten are inherited, and are largely dependent on the variety; the index of heritability for protein content in wheat is 0.83. Most industrial countries set a number of absolute grain quality requirements on any new varieties which are developed; the accepted standards are that there must be a protein content of no less than 14% protein and 28% gluten.

At the IVth Congress of the European Association for Research on Plant Breeding in Cambridge in 1971, the winter wheat Bezostal 1 was recognized as the best in the world for its adaptability to growing conditions and for yield. While most of the old varieties were produced by selection, Bezostal 1 was produced by hybridization; nowadays, non-intraspecies hybridization (i.e., hybridization of close relatives) is giving way more and more to distant hybridization, to crossing plants which belong not only to different species, but even to different genera. The results from crossing cultivars with plants growing in the wild are especially interesting, indeed, that is how the wheat-couch grass hybrids arose, and how mankind created a new grain crop, never before found on Earth, called triticale. The name is derived from the genus names for wheat and rye, as triticale was obtained by distant hybridization of the two.
In recent years, new methods for controlling heredity, over and above the well-known techniques of selection and crossing, have appeared on the scene. These make use of genetic engineering techniques, one of which is genetic control of heterosis. Heterosis is the rather higher productivity and vigour characteristic of first-generation hybrids, i.e. of the offspring of crosses between different plant forms. The resulting plants develop unusually sturdy stems, roots and leaves and give very high yields; also, their seeds are much higher in proteins and fats than the parent forms. Plants of this kind have greater-disease resistance and can shrug off adverse weather conditions. Underlying heterosis is the law of nature that in a healthy organism, the genes which favour growth and development are dominant. If an organism has two genes, one for and one against growth, the pro-growth gene wins out. Heterosis is not found very often in nature, and the unusual characteristics of the offspring are often lost. One way of not losing these characteristics is through polyplody, a phenomenon which is widespread in nature. Polyplody is the existence within a species of forms with a larger set of chromosomes than the norm. The increase in the number of chromosomes goes hand-in-hand with changes in the appearance of the plant, which has more flowers, seeds and fruit; for example, the seeds of polyploid rye, buckwheat and maize are usually 50 to 100% larger than normal. Scientists have developed a method of experimental polyplody which enables them to alter the number of chromosomes using special techniques, and the polyploids are used as material for subsequent selection and the creation of new varieties.

Modern selection techniques make use of yet another characteristic of living organisms, their ability to mutate; i.e., to suddenly manifest new characteristics and transmit them to their descendants. The causes of mutations are extremely varied: a sharp change in temperature, chemical compounds brought to earth by rain, a change in the intensity of ultraviolet irradiation and so on. To obtain mutations artificially, radiation, radioactive substances and chemicals (mutagens) are used.

In recent years, selection techniques have been enriched by the extremely interesting discoveries given us by the geneticists. In this period of change, we are seeing the birth of a new direction in science: genetic engineering. This new science comprises a whole system of methods which operate directly on the genes: splitting or fusing them, patching them into the genetic code in cell or tissue cultures from experimental organisms, transferring hybrid DNA into other organisms and so on.

One should not take a high protein and gluten content and assume that it is the level that is characteristic for the type, as they display great variability, which also includes variability over a geographical cross-section and depending on climate, soil characteristics and agricultural techniques. A single variety will have a different protein content as we move from south-west to north-east, with a clear downwards trend as we go, which goes to show that in developing new varieties, we have to take into account the climatic conditions in the territories for which they are earmarked.

The variations in the protein content of grain as affected by the agricultural techniques employed may be as much as 8% in a given year; soils, pre-crop crops and fertilizer inputs affect grain quality. The highest winter wheat quality indices are obtained when it is put in after full fallow or legumes; the high yields can be put down to the large quantities of
soluble nitrogen compounds (nitrates) which accumulate in leaving land fallow and give rise to the best conditions for plant nutrition. Raising wheat after maize gave a poorer quality of grain. At the same time, the effect of the precursor crops on grain quality also depends on agrometeorological conditions. In years with a severe moisture deficit, the effect of non-fallow precursors on this index was slight. In some cases, the protein content of winter wheat put in after green fallow or non-fallow precursors is close to the content obtained after full fallow, and may occasionally even be higher.

With the crop rotation patterns of today, filled up as they are with grain and row crops, the problem of improving grain quality cannot be solved just by putting it in after a better precursor crop. A whole set of measures is required, of which one of the most important is the use of fertilizers. Putting mineral fertilizers in after the plough every year at nitrogen doses of 60 kg or more of the active principle improves grain quality. A particularly large increase in protein content is observed when the crop is treated with ammonium nitrate at the milky/waxy ripeness stage. The treatment causes bluing and is used to obtain strong wheat. Putting on 20 to 30 kg per hectare increases gluten content by 3% and protein content by 1%.

Grain protein content and gluten quality are very variable over a geographical cross-section, depending on the climate and on soil characteristics. As we travel from the west to the east and south-east into drier regions, protein and gluten contents rise, i.e., grain quality increases. We use as a criterion of dryness the mean hydrothermal coefficient for June and May-August, as the hydrothermal coefficient increases, so protein and gluten content drop. That this should be the case confirms how enormously important climate is in dictating protein content.

It should be pointed out that the fluctuations in protein and gluten content in rye are insignificant in comparison with wheat. This can be put down to the fact that rye is generally less sensitive to unfavourable conditions of weather and climate (it is less fussy about moisture conditions and is more drought-resistant). Even so, it is still very responsive to improvements in agrometeorological conditions and agricultural techniques.
Bibliography (In Russian)

<table>
<thead>
<tr>
<th>Author(s)</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kuperman, I.A. and</td>
<td>Respiratory gas exchange as a factor in the plant productivity process, Nauka, Novosibirsk, 184 pp.</td>
</tr>
<tr>
<td>Polevoy, A.N., 1983</td>
<td>The effect of agrometeorological conditions on winter wheat harvest quality, Meteorology and Hydrology 10, 92-98.</td>
</tr>
<tr>
<td>Stroganova, M.A. and</td>
<td></td>
</tr>
<tr>
<td>Polevoy, A.N., 1982</td>
<td></td>
</tr>
</tbody>
</table>