WORLD METEOROLOGICAL ORGANIZATION

Agricultural Meteorology

CAgM Report No. 70

DEFINITION OF AGROMETEOROLOGICAL INFORMATION

REQUIRED FOR FIELD AND BUSH CROPS

by

(Dr S. Al-Hazim, Dr B.C. Biswas, Prof. K.G. Hubbard
and Mr P.S.N. Sastry*)

*Co-ordinator of the Joint Rapporteurs

WMO/TD-No. 757
Geneva, Switzerland
July, 1996
"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."
DEFINITION OF AGROMETEOROLOGICAL INFORMATION

REQUIRED FOR FIELD AND BUSH CROPS

by

(Dr S. Al-Hazim, Dr B.C. Biswas, Prof. K.G. Hubbard
and Mr P.S.N. Sastry*)

*Co-ordinator of the Joint Rapporteurs

WMO/TD-No. 757
Geneva, Switzerland
July, 1996
# CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>PREFACE</td>
<td>ix</td>
</tr>
<tr>
<td>CHRONOLOGY OF EVENTS AND SUBJECT AREAS</td>
<td>xi</td>
</tr>
<tr>
<td>TERMS OF REFERENCE FOR RAPPORTEURS</td>
<td>xiii</td>
</tr>
<tr>
<td>CHAPTER I - REPORT ON BANANA CROP - by Mr P.S.N. Sastry</td>
<td>1</td>
</tr>
<tr>
<td>1.1 INTRODUCTION</td>
<td>3</td>
</tr>
<tr>
<td>1.2 THE BANANA CROP</td>
<td>3</td>
</tr>
<tr>
<td>1.2.1 Varieties and nomenclatures</td>
<td>3</td>
</tr>
<tr>
<td>1.2.2 Description of the plant</td>
<td>3</td>
</tr>
<tr>
<td>1.3 THE BANANA CLIMATE</td>
<td>4</td>
</tr>
<tr>
<td>1.3.1 Growing conditions</td>
<td>4</td>
</tr>
<tr>
<td>1.3.2 Time of planting</td>
<td>8</td>
</tr>
<tr>
<td>1.3.3 Leaf emergence and expansion</td>
<td>8</td>
</tr>
<tr>
<td>1.4 IRRIGATION AND WATER REQUIREMENTS IN BANANA</td>
<td>8</td>
</tr>
<tr>
<td>1.4.1 Water requirements</td>
<td>8</td>
</tr>
<tr>
<td>1.4.2 Evapotranspiration</td>
<td>9</td>
</tr>
<tr>
<td>1.4.3 Crop coefficients</td>
<td>10</td>
</tr>
<tr>
<td>1.4.4 Water logging</td>
<td>10</td>
</tr>
<tr>
<td>1.4.5 Drought and heat</td>
<td>10</td>
</tr>
<tr>
<td>1.4.5.1 Advective conditions</td>
<td>11</td>
</tr>
<tr>
<td>1.5 EFFECT OF WIND</td>
<td>11</td>
</tr>
</tbody>
</table>
1.6 LIGHT INTENSITY AND BANANA GROWTH .......................... 12

1.7 THE TEMPERATURE REGIME AND BANANA DEVELOPMENT ...... 13

1.7.1 Effect of low temperature and frost occurrence on the phenology 14 of banana crop in the sub-tropics ...........................................
1.7.2 Temperature and bunch initiation in banana crop ............ 14
1.7.3 Temperature optima for fruit growth .......................... 14
1.7.4 Optimum temperature for nutrient uptake in banana ........ 15
1.7.5 Ripening temperature and keeping quality in banana ........ 15
1.7.6 Pulp firmness and shelf life variations with temperature .... 15
1.7.6.1 Estimation of shelf life ........................................... 16

1.8 PESTS AND DISEASE IN BANANA CROP AND WEATHER 17 CONDITIONS .................................................................

1.8.1 Sigatoka disease .................................................. 17
1.8.1.1 Temperature thresholds ........................................ 17
1.8.1.2 Germination ..................................................... 17
1.8.1.3 Germ tube growth ............................................. 18
1.8.1.4 Incubation period ............................................. 18
1.8.1.5 Other general observations ............................... 18
1.8.1.6 Approaches to forecasting of sigatoka disease .......... 19
1.8.2 Fungus diseases of pre-harvest fruit .......................... 19
1.8.2.1 Pitting disease ............................................... 19
1.8.2.2 Brown spot .................................................... 19
1.8.3 Aphids ............................................................ 19
1.8.4 Chilling injury .................................................... 19
1.8.5 Sun scorch, sun burn and sun scald ........................... 20
1.8.6 Fungal diseases of post-harvest fruit ......................... 20
1.8.6.1 Crown rot ..................................................... 20
1.8.6.2 Finger rot ..................................................... 20
II.5 TEMPERATURE AND GROWTH OF COTTON ............................................. 42

II.5.1 Seed germination and emergence ................................................. 42
II.5.2 Vegetative growth ........................................................................ 43
II.5.3 Flowering .................................................................................... 43
II.5.4 Bud initiation ................................................................................ 43
II.5.5 Night temperatures and growth .................................................... 44
II.5.6 Day/night temperatures .................................................................. 46
II.5.7 Leaf area ....................................................................................... 47
II.5.8 Node of the first fruiting branch ..................................................... 47
II.5.9 Flowering ..................................................................................... 47
II.5.10 Boll development and production ............................................... 48
II.5.11 Mean daily temperatures and boll development ................................ 48
II.5.12 Boll period .................................................................................. 48
II.5.13 Temperature and boll retention .................................................... 48
II.5.14 Temperature and fruit set ............................................................ 49
II.5.15 Growing degree days ................................................................... 53
II.5.15.1 Prediction model for boll opening using degree days ...................... 53
II.5.16 Temperature and fibre quality ..................................................... 53
II.5.17 Temperature and chilling injury ................................................... 53

II.6 EVAPOTRANSPIRATION AND WATER NEEDS IN COTTON ............ 55

II.6.1 Water use ..................................................................................... 55
II.6.2 Water stress .................................................................................. 61
II.6.2.1 Effects of water stress ................................................................. 61
II.6.2.2 Stomatal conductance in sunlit and shaded leaves ....................... 61
II.6.2.3 Influence of advective conditions .............................................. 63
II.6.3 Canopy-air temperature difference and water stress ....................... 63
II.6.3.1 Thermal stress index ................................................................... 63
II.6.3.2 Effect of irrigation scheduling on canopy temperatures ............... 64
II.6.3.3  Effect of water logging on canopy temperature .................. 64
II.6.4  Drought and crop yields ........................................... 64

II.7  SUNSHINE, LIGHT INTENSITY AND CROP GROWTH ................. 67
II.7.1  Cloudiness .......................................................... 67
II.7.2  Critical light intensity ............................................. 67
II.7.3  Light transmission .................................................. 68
II.7.4  Phosynthetically active radiation and lint yield .................... 68
II.7.5  Albedo and microclimate ........................................... 68

II.8  INSECT PESTS AND DISEASES IN COTTON AND WEATHER FACTORS ........................................ 71
II.8.1  Pests in cotton ....................................................... 71
II.8.1.1  Boll Weevil ........................................................ 71
II.8.1.2  Pink Boll Worm .................................................... 71
II.8.1.3  Spotted Boll Worm ............................................... 72
II.8.1.4  Boll Worm ......................................................... 72
II.8.2  Cotton Jassids ......................................................... 72
II.8.3  Cotton Aphids ......................................................... 72
II.8.4  Cotton diseases ....................................................... 74
II.8.4.1  Seedling diseases ................................................... 74
II.8.4.2  Seed decay .......................................................... 75
II.8.4.3  Rhizoctonia Solani ................................................ 75
II.8.4.4  Pythium spp. ........................................................ 75
II.8.4.5  Colletotrichum spp. ................................................. 76
II.8.4.6  Theilaviopsis basicola .............................................. 76
II.8.5  Bacterial Blight ....................................................... 76
II.8.5.1  Verticillium wilt ..................................................... 77
II.8.5.2  Fusarium wilt ....................................................... 77
<table>
<thead>
<tr>
<th>Section</th>
<th>Topic</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>II.8.6</td>
<td>Alternaria leaf spot</td>
<td>77</td>
</tr>
<tr>
<td>II.8.7</td>
<td>Cercospora leaf spot</td>
<td>78</td>
</tr>
<tr>
<td>II.8.8</td>
<td>Grey or False Mildew</td>
<td>78</td>
</tr>
<tr>
<td>II.9</td>
<td>RECOMMENDATIONS AND CONTRIBUTION TO CARS</td>
<td>78</td>
</tr>
<tr>
<td>II.10</td>
<td>BIBLIOGRAPHY</td>
<td>80</td>
</tr>
<tr>
<td>II.11</td>
<td>Acknowledgements</td>
<td>87</td>
</tr>
</tbody>
</table>

CHAPTER III - REPORT ON SOYA BEAN CROP, by K.G. Hubbard 89

III.1 INTRODUCTION 91

III.2 AGROMETEOROLOGICAL INFORMATION IN FARMING 91

<table>
<thead>
<tr>
<th>Subsection</th>
<th>Topic</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>III.2.1</td>
<td>Choice of Cropping System</td>
<td>91</td>
</tr>
<tr>
<td>III.2.2</td>
<td>Sowing Decisions</td>
<td>92</td>
</tr>
<tr>
<td>III.2.3</td>
<td>Timing and nature of cultivations, including field preparation</td>
<td>93</td>
</tr>
<tr>
<td>III.2.4</td>
<td>Timing and nature of sprays and fertilizer</td>
<td>93</td>
</tr>
<tr>
<td>III.2.5</td>
<td>Irrigation amount and frequency</td>
<td>94</td>
</tr>
<tr>
<td>III.2.6</td>
<td>Harvest decisions</td>
<td>94</td>
</tr>
<tr>
<td>III.2.7</td>
<td>Post harvest operations</td>
<td>94</td>
</tr>
<tr>
<td>III.2.8</td>
<td>Duration of growth</td>
<td>95</td>
</tr>
<tr>
<td>III.2.9</td>
<td>Rage of growth</td>
<td>95</td>
</tr>
<tr>
<td>III.2.10</td>
<td>Yield and stress</td>
<td>95</td>
</tr>
</tbody>
</table>

III.3 BIBLIOGRAPHY 96
PREFACE

The Commission for Agricultural Meteorology of the WMO had prepared reports on agrometeorology of several food and cash crops through members of working groups and rapporteurs appointed for the purpose. Reports on agrometeorological aspects of different crops such as rice, groundnut, soyabean, sugarcane, banana have been prepared and published as WMO Technical Notes or CAgM reports from time to time. In 1991 the CAgM established several working groups and appointed rapporteurs for defining agrometeorological information required for different crops (food crops, field and bush crops, commercial tree crops, tuber and pulse crops and vegetable crops) for use in agricultural operations. The objective had been to arrive at precise definitions regarding threshold values of agrometeorological elements affecting growth and development of crops. Accordingly the rapporteurs on various crops sent questionnaires through WMO to obtain information from the different Member countries.

The definitions provided in this report are representative values based on a few individual experiments reported on individual varieties of crops from different parts of the world and on replies received to the questionnaire circulated through the WMO Secretariat to Member countries. It is hoped that the information provided would serve the purpose of providing threshold values for analysing meteorological/climatological information tailored to crop growth and development.

The present attempt by CAgM is to bring at one place all limiting and threshold values with crop specificity. Evidently, rainfall and temperature have taken greater importance over other elements since these have dominating influence on several aspects of crop growth in both pre- and post-harvest agricultural operations. This report also brings out the shortfalls in databases on different crops. More research information is needed to refine the thresholds which are extremely useful and essential for operational management of the crops.

The next step should be to update the information provided and formulate tables and graphs depicting the various relationships for day-to-day operations. This cannot be achieved overnight, but its importance as a priority area for specific observations from field experiments will undoubtedly be recognized by all agrometeorologists. To make them readily useable, it is essential to reanalyse historical climatological data with specific reference to the threshold values for periods corresponding to the phenology of the different crops as part of CARS programme of WMO. It is hoped that future attempts at research, experimentation and technology development in the Member countries would take this into consideration and develop information in this framework, adding their own innovative features.

P.S.N. Sastry
Co-ordinator of Joint Rapporteurs
on Field and Bush Crops
CHRONOLOGY OF EVENTS AND SUBJECT AREAS

The Commission for Agricultural Meteorology at its tenth session (Florence, 1991) appointed experts to work jointly as Rapporteurs on Definition of Agrometeorological Information Required for Commercial Field and Bush Crops. The composition of the group and their terms of reference were as follows:

Prof. K.G. Hubbard
Department of Agril Meteorology
242 L.W. Chase Hall
University of Nebraska
P.O. Box 830728
Lincoln, NE 68583-0728
USA

Rapporteur
Crop: Soyabean

Dr B.C. Biswas
Director (Agrimet)
Meteorological Office
PUNE - 411 005
India

and

Rapporteurs
Crop: Cotton

Dr S. Al Hazim
Meteorological Department
P.O. Box 4211
DAMASCUS
Syrian Arab Republic

Mr P.S.N. Sastry*
Division of Agricultural Physics
Indian Agricultural Research Institute
NEW DELHI - 110 012
India

Rapporteur
Crop: Banana

* also Co-ordinator of the Joint Rapporteurs
TERMS OF REFERENCE FOR RAPPORTEURS ON "DEFINITION OF AGROMETEOROLOGICAL INFORMATION REQUIRED FOR COMMERCIAL FIELD AND BUSH CROPS (Res. 12 (CAGM-XI))

(a) To describe in quantitative terms agrometeorological information required by users for both planning and operational management of the crops;

(b) To formulate such information for different stages of crop growth and development, from sowing to harvest and post-harvest (storage and transport) operations in a readily useable, user-oriented form;

(c) To provide examples from Member countries of the use of such information;

(d) To summarize in detail social, economic and environmental benefits of such information;

(e) To identify potential contribution to CARS-Food;

(f) To submit annually information on the progress of activities and a final report to the president of CAGM.

Specific objectives:

To develop and provide to Members the techniques and methods

(a) To describe in quantitative meteorological terms the information that is required by the different users in agriculture;

(b) To formulate this information in terms permitting the user to exploit it easily. This is a very high priority objective without which no other specific objective can be adequately implemented.

For fulfilling the task assigned to the rapporteurs, in June 1993, the co-ordinator formulated a framework which could form the contents of the report. WMO had also provided the notes prepared by Prof. J. Elston as guidance for the format of the final report. These provided the basis for presentation of the information regarding each crop.

A comprehensive questionnaire in respect of cotton, banana and soyabean crops prepared by the rapporteurs was circulated to Member countries by the Secretariat in August 1993 for obtaining information on crop and weather data.
The Final Report

Framework:

Information was broadly required for three major purposes:

(a) Long- and short-term planning and management at national or regional level (mostly needed by government organizations, policy makers and industries). Such information should include:

- estimates of production and quality
- aerial estimates of water balance
- predictions of epidemics
- significant weather events such as cyclones, hail, flood, heat wave, cold wave, etc. and their impact;

(b) Academic understanding and teaching (scientific research institutions, universities, etc.);

(c) Practical application under field conditions for day-to-day agricultural operations, contingency planning and crisis management in times of abnormal and adverse weather occurrences.

While the parameters on which observations and information is needed are more or less the same, the instrumentation, accuracy requirements, frequency of observations, network spacing, approaches, methods and techniques of analysis, time and space scale over which the analysis is needed all differ widely from one purpose to the other but at the same time they are complementary in nature. This point was kept in view while formulating definitions for agrometeorological information for multifarious purposes.

Research

Problems of transfer of data obtained under controlled conditions to actual dynamic field conditions which have diurnal and local variations, should be further studied.

Secondly, information can be categorized as "minimum essential requirement" - one which serves several common purposes, and others as "optional" which serve specific purposes. A definition of "readily useable form" needs to be made, depending on the end-use visualized.
Suggested contents of report

General information about the crop:

About the plant - origin, distribution, genetic nomenclature;
Brief description of the plant and morphological characters;
General climatic conditions, world distribution and production;
Rooting habits;
Optimum soil physical properties;
Planting season;
Phenological events and their duration (days/weeks);
Range of water requirements; irrigation practices;
Light saturation value, temperature thresholds for different phases of the life cycle of the plant;
Common pests and diseases, their normal time of occurrence;
Commodity harvested - as grain, oil, fruit or tuber;
Storage and transport practices.

Definition of agrometeorological information is required for the following:

Choice of cropping system;
Choice of sowing date;
Timing and nature of cultivations, seed bed preparation.

Questions to be answered based on agrometeorological information in terms of probabilities:

When do you expect pre-sowing rains;
When do you expect sowing rains;
When do you expect the rains to cease;
What is the length of growing season available or a particular crop.

Land workable days (probability in the season)
Information base for water harvesting for rainfed crops

Probable periods and amount of run off available for low rainfall, normal and high rainfall years.

Decision on fertilizer application for rainfed crops

Question: How much fertilizer should be applied and when?
Decision depends on information on initial moisture condition in the soil at the beginning of the cropping season (sowing time). Timing depends on rainfall and wind conditions.

**Drought and irrigation management**

What are the evaporation (AET, PET, PAN) rates in the different phenophases?

What are the crop water requirements?

What is the duration of consecutive dry and wet spells for different levels of rainy or dry days? (Rainy day need not be defined in the conventional manner. It can have different limits such as days with 5mm, 7mm or 10mm; similarly, dry day can be defined with different limits of rainfall and statistics worked out in each case depending on the crop for ready use.)

What are the days/periods when advective influence could be expected during the crop season with reference to growth phases?

What is the nature of drought occurrence with respect to phenophases of crop.

**Amelioration from water logging and floods**

What are the water logging/flood prone weeks?
What is the recession time of the water logging/flood?
What are the rainfall intensity-duration relationships?
What are the rainfall-run off relations?
What is the soil water balance under bare and cropped conditions in the root zone?

What is the soil water balance pattern in the rootzone of the crop in (a) high rainfall years, (b) normal rainfall years, and (c) low rainfall years?

**Heat and cold waves**

What are the periods of frost occurrence?
What is the weather during cold wave periods during the different phenophases?
What are the lowest minimum temperatures expected and what are the areas affected where the crop is grown?
What are the periods of heat wave occurrence?
How high will the temperature rise?
Pest and disease management

Control against pests and diseases
Development of disease warning system

Questions:

When can we expect climatic conditions to be favourable for initiation of pest or disease?
What are the favourable regions?
Are there any climatic situations and preferred areas associated with spread of pest and disease for any weather system?
What are the best times of the day for spraying?

Harvest and post-harvest operations

Probable harvest date
Post-harvest operations
How many bright sunshine hours can one expect?
What is the best time for transport of produce after harvest?
What are the best storage conditions of temperature and humidity?

Information needed by the plant breeder to tailor the crop to weather

Information needed for manipulation of crop timing and other practices for stable production.

Special information for:

Contingency planning (mid-season correction for rainfed crops);
Crop weather modelling both statistical and dynamical approaches;
Light intensity distribution within the crop;
Net radiation from cropped surfaces;
Photosynthetically active radiation;
Photosynthetic rates, response curves.

Information on associated factors commonly used for agrometeorological work - plant and soil factors.

The above is not an exhaustive study. However, the rapporteurs were requested to address the questions raised above.
I. REPORT ON BANANA CROP

by

Mr P.S.N. Sastry (India)
(Rapporteur on Definition of Agrometeorological Information Required for Banana Crop)
DEFINITION OF AGROMETEOROLOGICAL INFORMATION FOR BANANA CROP

I.1 INTRODUCTION

Agrometeorological aspects of banana crop has been sufficiently documented over a period of time. Operational management of the crop for optimization and maximization of yields needs information on specific and well defined threshold values. Climatological data which are designed to cater to general weather information for multifarious purposes do not meet this need. For this, various threshold values from field and laboratory experiments reported in literature, specific to any particular crop such as banana, are to be collated and presented in a form which can be used for recasting or reanalysing climatic data with particular reference to growth phases of the crop. In the pages to follow, agrometeorological information on banana crop reviewed earlier (Sastry, 1988) has been utilized to define threshold values of weather elements for different crop management purposes in the pre- and post-harvest stages of the banana crop.

I.2 THE BANANA CROP

Banana is one of the oldest fruit crops known to the world and its potential as a fully fledged industry is yet to be exploited in several part of the world. It is generally agreed that all the edible bananas are indigenous to the warm, moist tropical regions of Southeast Asia probably in the mountainous region where India (Assam), Myanmar and Thailand meet (Hayes, 1957). Details about its origin, spread, general climatic requirements, and several aspects of agrometeorology of banana crop have been extensively reviewed by Sastry, (1988).

I.2.1 Varieties and nomenclatures

The bananas and plantains belong to the genus Musa of the family Musaceae. Majority of the cultivated bananas are derived from the species M. acuminata an M. balbisiana. Edible bananas have 22, 33 or 44 chromosomes, the basic number being n = 11 so that these varieties are respectively diploid, triploid or tetraploid. Triploid cultivars are the most common.

I.2.2 Description of the plant

The banana is a tall perennial plant with an underground stem known as the “corm”. The roots are adventitious and spread in all directions (up to 6m) forming a dense mat and also vertically down (about 1m). The aerial shoots are non-woody pseudostems composed of tightly packed leaf sheaths rolled around each other in a near circular shape. The aerial shoots “suckers” arise from the lateral buds on the rhizome. The leaf blade emerges from the middle of the stem and unfurls slowly. The pseudostem carried about ten expanded leaves (Summerville, 1944). The shoot flowers only once and as the apex becomes reproductive, no further leaves are initiated. The flowering stem emerges in the leaf crown and hangs down under the influence of gravity, bearing flower clusters. Each cluster bears 12-20 flowers in two rows covered by bract. A fruit cluster is called a “hand” and a single fruit a “finger”.
I.3 THE BANANA CLIMATE

The banana is basically a plant of humid tropics but is adapted to a wide range of climatic conditions from wet tropical to dry sub-tropical area (lat. 30°N to 30°S). Deep, well-drained loamy soil with adequate organic matter is considered ideal for its cultivation.

The most suitable climate is the one with warm moist weather throughout the year without strong winds. Favourable factors determining its distribution are: rainfall in excess of 100 mm per month and a temperature range of 10-40°C with an optimum between 25-30°C and a mean minimum temperature of 15.5°C.

I.3.1 Growing conditions

Broadly speaking, banana cultivation is widely practised in areas with >120 cm isohyet and >15.5°C isotherm. The factors that operate against extension of its cultivation are areas with:

(a) long dry season;
(b) frost occurrence;
(c) cool winters;
(d) hot winds in summer; and
(e) stormy or cyclonic winds.

Each of these parameters needs to be defined to delineate zones in a country which are adverse for optimum growth conditions for banana and for planning ameliorative measures where possible. Such definition is also useful to demarcate zones where:

- climates in which bananas suffer little or no seasonal growth check and in which irrigation is not essential;
- climates in which bananas regularly suffer seasonal check to growth either by drought (as in dry season in Trinidad) or by a combination of drought and low temperature (as in Queensland);
- climates where irrigation is essential throughout the growing season.

(a) Long dry seasons:

Monsoon areas of the world where rainfall is seasonal (occurs only for three to four months) such as those found in Asia can be cited as an example. It has been mentioned earlier that minimum 100 mm rainfall per month is the most optimum condition for growth of banana. In areas with long dry seasons, obviously banana can be successfully grown only under irrigated conditions. For a rough estimate, stations with absence of rainfall for more than three consecutive months in a year with rainfall less than 100 mm per month should be considered as places with long dry season for banana growth. Such a criteria would be useful for analysis at a regional scale.
(b) **Frost occurrence:**

This information is generally available from routine climatological analysis and can be extracted from general climatological tables or maps and depicted for banana growing regions of a country.

(c) **Cool winters:**

All regions with mean monthly minimum air temperatures of $10^\circ\text{C}$ or less may be taken as areas with cool winters with respect to banana crop.

(d) **Hot winds in summers:**

Temperatures $>40^\circ\text{C}$ affect growth of banana. Mean monthly maximum air temperatures $>40^\circ\text{C}$ can be taken to define prevalence of hot summers with respect to banana growth.

Experimental results of Philip and Spector, (1970) on the effect of cool and hot seasonal conditions on fruit quality and yield in the West Indies serve to illustrate the need for such definitions. This further helps in development of research information to ensure availability of high yields of good quality fruit through the year, in banana growing regions which experience both cool winters and hot summer conditions.

(e) **Stormy and cyclonic winds:**

Frequency of occurrence of cyclones and maps of cyclonic tracks are helpful in deciding the suitability or otherwise for banana growing.

Agroclimatic zoning for banana can be done using:

(i) monthly mean minimum air temperatures of $>15^\circ\text{C}$ in winter which are optimum for growth of banana;

(ii) marginal areas less affected by cool winters (monthly mean minimum air temperatures in winter between $10^\circ$ and $15^\circ\text{C}$); and

(iii) probable areas of impedance of inflorescence and malformation of bunches due to cool winters (areas with monthly minimum air temperatures $<10^\circ\text{C}$).
An example of Agroclimatic regions of Peninsular Malaysia with specific reference to suitability of banana growth is shown in Figure I.1.

Figure I.1 Agroclimatic regions of peninsular Malaysia (Malaysian National Meteorological Service; legend overleaf)
Seven agro-ecological zones of banana cultivation in Malaysia (Figure 1.1).

(i) **The Northwest** (Regions 1-6) has four months of clear and regular dry season. Only suitable for the hardy cooking banana.

(ii) **The West Coast** (Regions 7-12)

Comprises of all lowland areas west of the main range with more equable seasonal distribution of rainfall.

Most suitable for banana cultivation, both dessert and cooking types.

(iii) **The South** (Regions 13-15)

- Absence of regular dry seasons, enjoys well distributed rainfall throughout the year
- Highly suitable for banana cultivation of all types

(iv) **The East Coast** (Regions 16, 22, 25, 26) with two main climatic features

(a) Very high amounts of rainfall for three months of the year reaching 1500 mm.

(b) A regular dry season for two-three months.

Not suitable for banana cultivation, prone to wind damage and floods.

(v) **The Central Interior** (Regions 17-21)

Has two short dry seasons, of about one month each, followed by rainfall, especially afternoon showers.

Banana cultivation is suitable.

(vi) **The Northern Interior** (Regions 23-24)

A clear dry season for one-two months, followed by a slow increase of rainfall throughout the year.

Suitable for banana cultivation especially on fertile soils at the foothills.

(vii) **The Highlands**

Rainfall increases with elevation but is less variable and decrease in intensity. The limiting factor to banana cultivation in low temperatures.

Banana cultivation is feasible up to the altitude of 1000 m above sea level.
1.3.2 Time of planting

In general, in several countries where adequate irrigation is available, or with well distributed rainfall occurring throughout the year, planting is done round the year (Sastry, 1988). However, cold (<15°C) and very hot (>40°C) months are avoided for planting. In countries with monsoon regimes with a dry season, bananas are usually planted just before the beginning of the rainy season, while spring planting is the most common feature in the sub-tropics.

The effect of date of planting on bunch and plant characteristics in banana is considerable, as illustrated in the table below. Hence choice of planting time is important.

<table>
<thead>
<tr>
<th>Date of planting</th>
<th>Months to harvest</th>
<th>Bunch wt. (kg)</th>
<th>% of fruit extra-large</th>
<th>Greenlife of fruit (days)</th>
<th>Pseudostem Ht. at harvest</th>
</tr>
</thead>
<tbody>
<tr>
<td>25 January</td>
<td>12.7</td>
<td>29.5</td>
<td>91</td>
<td>24</td>
<td>213</td>
</tr>
<tr>
<td>18 March</td>
<td>12.5</td>
<td>31.9</td>
<td>88</td>
<td>24</td>
<td>245</td>
</tr>
<tr>
<td>10 June</td>
<td>11.6</td>
<td>26.5</td>
<td>82</td>
<td>24</td>
<td>227</td>
</tr>
<tr>
<td>4 August</td>
<td>10.9</td>
<td>24.6</td>
<td>82</td>
<td>19</td>
<td>227</td>
</tr>
<tr>
<td>27 September</td>
<td>11.2</td>
<td>23.6</td>
<td>77</td>
<td>14</td>
<td>215</td>
</tr>
<tr>
<td>1 December</td>
<td>12.7</td>
<td>28.1</td>
<td>90</td>
<td>31</td>
<td>223</td>
</tr>
</tbody>
</table>


This type of information on different varieties is useful in forecasting production times and for planning availability of fruit through the year in a uniformly distributed manner.

1.3.3 Leaf emergence and expansion

Leaf emergence, leaf expansion rate are both correlated with air temperature. A threshold value of 10°C has been arrived at by Turner (1970) for leaf emergence in banana below which it ceases to emerge. As mean air temperature rises from 10 to 25°C, production increase by one leaf per month per a 3.5°C rise in temperature (Turner, 1971; Robinson, 1981). For leaf expansion a critical value of 15.5°C had been cited by Summerville (1944).

1.4 IRRIGATION AND WATER REQUIREMENTS IN BANANA

1.4.1 Water requirements

As for any other crop, water requirements of banana vary according to topography, soil, climate and variety. Most of the practices followed for irrigating the crop in the different areas is by experience (Sastry, 1988). While no attempt would be successful to define water requirement of a crop, being location and variety specific, results of a few irrigation experiments based on the concept of "available water" reported in literature are summarized below.
Trocholias (1973), Ghavami (1974), Manica, et al., (1975), Pursglove (1972) put the minimum amount of water needed for good growth at 25 mm/week. This agrees with the practice followed in Queensland (Daniells, 1984) where irrigation is applied every 7 to 14 days with overhead system and every 2 to 4 days with under tree system. He observed that irrigation during the dry spells leads to 15-20% increase in yields.

In full sunlight, transpiration is estimated to be as high as 50mg/dm²/minute according to Champion (1963). A dwarf banana plant could consume 25 litres of water on a clear day, 18 litres on a partly cloudy day and 9.5 litres on an overcast day.

Effective rooting depth is around 70 cm and Shmueli (1953) observed that 65% of total water loss was taken up from top 30 cm of soil and only 5% from depths below 60 cm. Bunch number, fruit weight, hand and finger number and finger length all increase significantly with decreased moisture deficit (Trocholias, 1973).

Trickle irrigation is recommended since 70% of the root system is concentrated within a soil depth of 40 cm and confined to 60 x 60 cm square area at the base of the banana plant. Supplementary trickle irrigation at the rate of 3 litre/hour twice a week at 60 to 100% class A evaporation rate has been recommended by Trocholias and Murison (1981) for increase in bunch weight and finger number.

According to Champion 1963, quoted by Samson (1980), banana can easily take up to 30% of available water from the soil at field capacity. At 60% depletion of available water, wilting may occur resulting in stomatal closure and a reduced photosynthetic rate. Evaporation declines sharply when soil water is reduced from 2/3 to 1/2 field capacity (Shmueli, 1953). Investigations by Holders and Gumbs (1982; 1983a) showed that irrigation at 60 to 75% available water increased yields. Non-limiting supply of soil moisture around the time of floral initiation significantly increased female flower production and this was one of the critical periods identified by Holders and Gumbs for irrigation. In a study by Trocholias (1973) in New South Wales, the crop was irrigated when moisture deficits fell to 90, 80, 60 and 50% of available water. The most effective treatment was that with 90% depletion which produced double the yield compared to the unirrigated field.

Thus, it can be concluded that irrigation should be provided as soon as depletion reaches 90% of available water. This provides a common basis for working out water requirement of the banana crop depending on the soil type and crop variety at different growth stages. Irrigation time and frequency can be worked out on this basis.

1.4.2 Evapotranspiration

Evapotranspiration and crop coefficients are the parameters that are frequently needed for determination of irrigation amounts and its scheduling in the different phases of crop growth season. Turner (1972a) approximated evapotranspiration rate from banana using the following expression:

\[
ET = 0.9E_p \times W_a \quad Ep = \text{pan evaporation}
\]

\[
W_a = \text{available soil water as a fraction of field capacity.}
\]
In several countries, observations are made from wire mesh covered pan and the coefficient 0.9 can be neglected and pan evaporation can be directly multiplied by $\text{Wa}$ to obtain ET. In the tropics measured ET was observed to be 1.2 to 1.4 times of Class A pan evaporation for well-watered soil with complete canopy (Ghavami, 1973; Lahav and Kalmar, 1981) and represents the potential value. In the semi-arid region of Central India (Marathwada), reference crop evapotranspiration of banana was estimated as 2,538 mm for a crop duration of 510 days which works out to 5 mm/day on an average. For Sula valley of Honduras, with uneven rainfall distribution Ghvami (1973) arrived at an actual total evapotranspiration of 2,184 mm/year.

1.4.3 Crop coefficients

Crop coefficient values in banana of the order of 1.2 during rainy season, 0.7 during winter and 0.9 in summer have been reported (Bhattacharya and Kadhava Rao, 1985) for a monsoon region.

Being location specific, it is useful to work out crop coefficients along with regressions between ET from banana and pan evaporation in the different seasons within the growth cycle for use at different locations.

1.4.4 Water logging

Effect of water logging: Holder and Gumbs (1983b) have shown that water logging due to over irrigation decreases the bunch weight and other growth parameters. Bananas subjected to flooding by stagnant water for more than 48 hours are severely stunted in further development, and after 72-96 hours, there is no recovery of mature shoots (Stover, 1972). Flood injury is greater when strong sunlight and warm weather follow flooding.

Tables for probability of water logging for 24 hours, 48 hours, 72 hours, etc., need to be worked out depending on local soil conditions and evaporation rates in the different seasons (preferably on a weekly or ten-day basis) for design of drainage system for the banana plantations. The definition of rainfall value creating water logging conditions has to be worked out locally. Self recording rainfall data, gravimetric/volumetric soil moisture content for saturation, pan evaporation rates in the different seasons, rainfall-run off relations are the inputs needed for this.

1.4.5 Drought and heat

The banana plants need a continuous source of soil moisture for optimum growth. Some of the effects of drought conditions are - leaf damage, slowing down of leaf emission, short fingered fruit and softening of fruit before reaching harvest grade or premature ripening which result in reduced fruit quality.

The disposition of the lamina afford evidence of the state of hydration of the tissue. Under conditions of high transpiration, the petioles sag and the two halves of the laminae become flaccid and fold downwards (Samson, 1980) indicating presence of moisture stress. Lamina folding was closely associated with relative water content of the leaves, except under cool conditions (17°C) where lamina folded despite a relative water content of 97-99% in the leaf (Turner and Lahjav, 1983).
Relative water content of 97% would thus define the prevalence of moisture stress in banana plant when temperatures are above 17°C. Measurement of relative water content of banana leaf could be utilized to schedule irrigation on an operational level.

I.4.5.1 Adveective conditions

Adveective conditions imposed for a week or two by macro weather systems such as break monsoon periods (Sastry, 1979) in presence of wind speeds of the order of 10 km/day or more, create moisture stress in crops even under irrigated conditions. Such periods can be identified by computing the energy gain on any particular day using net radiation and pan evaporation data. Excedence of pan evaporation over net radiation is an approximate measure and good indicator of atmospheric drought conditions during the periods of energy gain by cropped surfaces from the surroundings.

Probable periods of adveective conditions can be worked out from climatic records. A formula such as Penman's (1948) can be used to estimate weekly net radiation in absence of measured net radiation values. Pan evaporation is the only other input required for estimation of energy gain by the crop. Since influence of moisture stress at different growth stages on final bunch and finger yield is different, the probability tables may include information on normal growth stages of banana for different planting dates practised in the area.

For operational work on assessment of heat stress and irrigation scheduling, real-time data on net radiation and pan evaporation can also be used for identification of presence of adveective conditions in an area and the approximate energy gain by the crop.

I.5 EFFECT OF WIND

The structure of the banana plant with large leaves, a heavy bunch of fruit and a shallow root system lends itself to destruction due to moderate or high winds.

Hearer (1964) suggests that the planting season should be so adjusted that during the cyclonic or high wind seasons, banana crop should not be in flower or near flower stage. Field experiments by Satyanarayana, et al., (1986) using seven monthly (first week) plantings showed that the percentage of blow ups due to summer squalls was the maximum with June plantings in coastal Andhra Pradesh (India). They recommended September plantings to escape this problem. Similar periods should be identified for other regions.

Wind velocities in the range of 25-30 kmph with gustiness rising to 50-55 kmph were shown to result in distortion of the crown. 50 kmph gustiness can be taken to define adverse wind conditions for banana plantation. Other periods, when bananas are subject to wind effects are, during windy conditions associated with dust storms, and cyclonic storms.

For operational purposes, forecast of tracks of depressions and cyclones with probable wind speeds >50 kmph, >90 kmph and the areas likely to be affected can be included in agroadvisories. Climatological information on average maximum wind speeds for each month as a ready made table is also useful. Wind breaks either natural forest belts or planting of pine trees are used in Queensland (Australia) to reduce damage from strong winds (Daniells, 1984).
I.6 LIGHT INTENSITY AND BANANA GROWTH

For examining the light sufficiency and saturation in banana, 20,000 lux has been identified by Samson (1980). This threshold value can be used to delineate optimum light intensity conditions for growth of banana in the different regions of a country on a weekly/monthly basis. It has been reported that shading up to 50% full sunlight does not have much effect on growth and yield (Murray, 1961). For a profitable use of this information, efforts should be made to generate data on light incidence at a place as percentage of full sunlight vs yield/month (bunch weight), and months to harvest, as illustrated in Figure I.2.

![Graph showing light intensity and banana growth](image)

**Figure I.2** Months to harvest and bunch weight in relation to light intensity (Murray, 1961)
1.7 THE TEMPERATURE REGIME AND BANANA DEVELOPMENT

Several growth and development processes like leaf production, leaf area, leaf unfurling, ripening of fruit, bunch weight, transportation and storage conditions are affected by the prevailing temperatures. Optimum conditions for some of these processes summarized and illustrated by Samson (1980) are reproduced in Figure 1.3.

![Graph showing temperature and banana development processes](Image)

Figure 1.3 Relation between temperature, growth and other processes in banana culture (Samson, 1980).
Turner and Lahav (1983) have arrived at the following optima:

<table>
<thead>
<tr>
<th></th>
<th>Minimum</th>
<th>Optimum Temperature °C</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leaf area increment</td>
<td>12.3</td>
<td>31.1</td>
<td>33.5</td>
</tr>
<tr>
<td>Leaf production</td>
<td>8.0</td>
<td>31.6</td>
<td>33.5</td>
</tr>
<tr>
<td>Dry weight increment</td>
<td>11.5</td>
<td>21.2</td>
<td>39.2</td>
</tr>
<tr>
<td>Relative growth rate</td>
<td>7.3</td>
<td>22.4</td>
<td>38.2</td>
</tr>
</tbody>
</table>

1.7.1 Effect of low temperature and frost occurrence on the phenology of banana crop in the sub-tropics

Frequency of occurrence of temperatures lower than 18°C and frequency of occurrence of temperatures near or below freezing point during the coldest months determine the suitability of a region for banana cultivation. Frost causes damage to the fruit but it does not destroy the plantation nor does it prevent regrowth in the following season during the warmer period. The length of the period of interrupted growth due to low temperatures plays an important part. The shorter the period of interrupted growth, better suited is the region for banana growing. Low temperatures also lengthen the period between shooting and maturity of the bunch affect time of the harvest. Period of interrupted growth can be worked out using the probabilities of occurrence of temperatures less than 18°C.

1.7.2 Temperature and bunch initiation in banana crop

Summerville developed a temperature index (Ts) to predict both bunch initiation and differentiation in banana. Ts is evaluated as a product of (a) total expanded leaf area; (b) hours of leaf exposure to day light, and mean temperature (°F) during the functional life of the leaf. Results showed that index values higher than 5.6 x 10¹¹ and 6.3 x 10¹ are needed respectively for bunch initiation and differentiation. Threshold value of Ts is higher in tropics. For operational purposes it would be useful to determine threshold Ts values for different locations and define them for forecasting bunch initiation in banana.

1.7.3 Temperature optima for fruit growth

Rate of growth of fruit in banana increases with temperature being positively correlated with degree days, above a base temperature of 14.4°C. In the range of temperatures 18-29°C the rate of increase in girth of the banana fruit was found to be linear (Ganry and Mayer, 1975).

An average temperature of 25.5°C during the month when the bunch is due for harvesting augments its weight; this effect increased up to 28-29°C (Hartman, 1929).

During the one or two months before harvest, average temperatures of the order of 26°C are found to be optimal for fruit growth; either higher or lower temperatures being detrimental to growth of the fruit. It was also observed to be related to mean daily temperatures in the range of 13-22°C (Turner and Barkus, 1982). An optimum temperature
of 27°C was proposed by Purseglove (1972) and 28-30°C by Ganry and Mayer (1975), for fruit growth.

These results show that a temperature of 27°C could be taken as the optimum temperature for fruit growth conditions in banana.

1.7.4 Optimum temperatures for nutrient uptake in banana

The influence of temperature on the concentration of nutrients in banana plants, the nutrient uptake rate, apparent root transfer coefficient were studied by Turner and Lahav (1985) under controlled day/night temperatures ranging from 17/10°C to 37/30°C. They concluded that temperature below 21°C reduced the concentration of all the elements in the plant except that of Iron. Maximum uptake rates of the nutrients were observed at day/night temperatures 29/22°C and 33/22°C.

1.7.5 Ripening temperature and keeping quality in banana

For transport to long distances (and export), the bunch is cut even when it is green and ripened under refrigerated conditions before marketing. By suitable adjustment of temperature and relative humidity, the colour quality and eating quality (pulp softening) of the fruit are maintained under optimum conditions at all stages of their handling. Studies by Rippon and Trocholias (1976) for skin colour and pulp firmness under different temperature conditions showed that the life of the fruit after ripening was mainly determined by the temperature at which ripening commenced. Temperature alters only the rate of ripening and hence ripening temperatures may be varied to produce the degree of ripeness desired within a given time frame.

Ripening can be accomplished at any (pulp) temperature between 14-20°C as eating quality (EQ) or skin colour quality (CQ) are not much affected at these temperatures (Peacock, 1980). He also showed that for temperatures around 14°C the weight loss due to ripening is less than 5% and these temperature values define the optimum levels for ripening.

1.7.6 Pulp firmness and shelf life variations with temperature

Studies on pulp firmness (penetrometer units) at optimum eating (EQ) and optimum colour quality (CQ) by Peacock (1980) showed the sensitivity of enzymal process to temperature variations. Fruit ripened at 14°C were found to be 16% more firmer at optimum EQ than that ripened at 24°C. Consequently, low ripening temperatures were recommended. In the 14 to 18°C range both EQ and CQ are optimum.

Ripening temperature against shelf life, eating and colour qualities were also studied by Peacock (1980). Shelf life was found to be decreasing exponentially with increase in temperatures. Temperature effects on eating (EQ) and colour quality (CQ) and shelf life reported by him are given below.
<table>
<thead>
<tr>
<th>Ripening temperature °C</th>
<th>Time of optimum CQ (days)</th>
<th>Shelf life (days)</th>
<th>Time to optimum EQ (days)</th>
<th>Shelf life (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>13.9</td>
<td>17</td>
<td>13</td>
<td>17</td>
<td>15</td>
</tr>
<tr>
<td>15.6</td>
<td>12</td>
<td>9</td>
<td>12</td>
<td>10</td>
</tr>
<tr>
<td>18.3</td>
<td>9</td>
<td>8</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>21.1</td>
<td>7</td>
<td>6</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>23.9</td>
<td>7</td>
<td>6</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>26.7</td>
<td>5</td>
<td>-</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>29.4</td>
<td>5</td>
<td>-</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>32.2</td>
<td>4</td>
<td>-</td>
<td>3</td>
<td>-</td>
</tr>
</tbody>
</table>

To a small extent, the period necessary for ripening can be lengthened or shortened while maintaining the desired quality of fruit by varying the temperature (Hardenburg et. al., (1986)) (see table below).

<table>
<thead>
<tr>
<th>Ripening schedule</th>
<th>Daily pulp temperature °C on day</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 days</td>
<td>1</td>
</tr>
<tr>
<td>5 days</td>
<td>17</td>
</tr>
<tr>
<td>6 days</td>
<td>17</td>
</tr>
<tr>
<td>7 days</td>
<td>16</td>
</tr>
</tbody>
</table>

1.7.6.1 Estimation of shelf life

Regression for long shelf life for colour and eating quality with temperature in the range of 14-24°C were worked out by Peacock (1980).

\[
\log \text{shelf life EQ} = -0.0371 T + 1.642 \\
(\text{T in °C})
\]

\[
\log \text{shelf life CQ} = -0.0326 T + 1.495 \\
(\text{T in °C})
\]

For operational purposes, regressions and tables such as those given as examples may prove useful. It may be added that these values need further refinement through research under local conditions depending on the variety, EQ and CQ desired by the consumers, transportation time and expected shelf life.

In summary, the recommended pulp temperatures and relative humidities for the different purposes may be stated as follows:
Temperature: °C

Shipping and holding green fruit 13 - 14
Ripening 14 - 20
Holding ripe fruit 13 - 14

Relative humidity:
Green or turning ripe fruit 90 - 95%
Ripe fruit 85%

I.8 PESTS AND DISEASES IN BANANA CROP AND WEATHER CONDITIONS

Pests and diseases that affect banana crop at different growth stages have been briefly reviewed by several researchers (Green (1963); Stover (1965; 1972); Wardlaw (1972). Sastry (1988)) reviewed them in relation to weather.

I.8.1 Sigatoka disease

The most important above-ground disease of banana is the sigatoka disease caused by the ascomycetous fungus Mycosphaerella Musicola Leach. The disease causes defoliation which may be so severe that fingers do not fill out, bunches remain small and stunted and the fruit turns soft on the plant. Three components, namely rainfall, dew and temperature, determine the time of appearance, intensity and movement of sigatoka inoculum.

I.8.1.1 Temperature thresholds

Temperature thresholds for the disease to appear at different phases of the banana crop are as follows:

I.8.1.2 Germination

8°C (lower threshold)
25°C (optimum)
38°C (upper threshold) (Brun, 1963).

Meredith (1970) placed the optimum temperature for germination of M. musicola conidia at 25-29°C.

For operational management of the disease, the other points to be noted are:

(a) Two types of spores, namely ascospores and conidial spores, differ slightly in their behaviour with respect to weather conditions.

(b) Perithecium production which discharges ascopores declines when minimum temperature is below 21°C even in presence of rainfall.

(c) Conidia are produced during the cooler night or early morning temperature conditions (Calpouzos, 1955).
Conidium production is very sensitive to temperatures below 22°C with an optimum at 26°C for ascospores and 26-28°C for conidia.

1.8.1.3 Germ tube growth

(a) For germ tube growth, optimum temperature falls between 25-28°C.

(b) Below 25°C rapid decline is noted. For ascospores growth, the optimum temperature is found to be 28°C. For conidia, two optima at 22 and 28°C are observed.

(c) 40 to 50 hours of favourable moisture conditions are needed for germ tube development (Meredith, 1970).

1.8.1.4 Incubation period

The incubation period, the time between spore germination and first appearance of yellow streak is found to depend on both climatic and plant factors (Meredith, 1970).

Higher rainfall and high daytime humidity hasten the incubation periods, while low rainfall and low humidity result in longer incubation period.

The duration of incubation period can range from minimum of 28 days in summer and 71 days in winter, with a maximum of 71 days in summer and 105 days in winter (Simmonds, 1966).

1.8.1.5 Other general observations

(a) Incidence of Sigatoka disease was lower on partially shaded leaves than those exposed fully to sunlight.

(b) Rainfall is an important factor to be considered for the appearance of streaks and spots in banana crop. Temperature has only a secondary role to play.

(c) Discharge of ascospores can begin one hour after a rainfall "trace" and 50% are discharged after six hours with a 2 mm rain.

(d) If leaves are wet, dissemination can begin within ten minutes and 85% are discharged in two hours.

(e) Continuous rainfall of long duration can release ascospores and wash them out of the air or off the foliage to the ground. But once spores are present on the leaf for 16 minutes or more, they cannot be easily washed out.

(f) Diurnal variations have been observed in ascospores depending on the season and rainfall patterns.

(g) Under favourable temperature conditions, perithecium production can sharply increase two to three weeks after two or more consecutive days with rain.
Critical periods of heavy infection vary from country to country depending on the seasonal conditions and need to be identified locally for prediction purposes.

I.8.1.6 Approaches to forecasting of sigatoka disease

The following factors (including meteorological factors) were used in correlation techniques for forecasting diseases and their control:

Correlation between changes in streak and spot development with temperature and relative humidity (Guyot and Cuielle (1958)).

Fortnightly rainfall amount (Calpouzos, et al., (1964)).

Correlation between time taken from unfurling of heart leaf and formation of streaks and time for spores to form (Brun, 1963).

Amount of inoculum available if weather becomes favourable for infection.

I.8.2 Fungus diseases of pre-harvest fruit

I.8.2.1 Pitting disease

Conidia germinate and form an appressorium on the green fruit with four to eight hours in a saturated atmosphere at optimum temperatures of 24-26°C (Stover, 1972).

I.8.2.2 Brown spot

This is a common blemish appearing on all varieties of bananas developing during the warm rainy season. Sporulation occurs within 16 hours at 23-26°C during periods of saturated atmospheric conditions (high relative humidity).

Viability: Spores may survive for 15 weeks under saturated conditions in the field. An inverse relationship was noted between spore survival and temperature. Spores may remain viable for 24 weeks at 14°C but for only one week at 45°C.

I.8.3 Aphids

In Egypt, aphid activity was found to be greater during winter months, December to January, with temperature ranging from 20-22°C and relative humidity around 60-70%. In India, during the rainy period with weekly rainfall of 20 to 40 mm and a temperature range between 24 to 27°C the highest population occurred. Below 15°C and above 31°C there is a rapid decline in the population.

These values approximately define the thresholds for aphid activity and can be used for developing prediction models.

I.8.4 Chilling injury

Chilling results from exposure of fruit to very low temperatures for a long time. Chilling may occur in the field when air temperatures drop below 13°C for several hours or when ground temperatures are around 5°C (Cann 1964).
1.8.5 Sun scorch, sun burn and sun scald

This occurs when peel temperatures reach 42°C.

1.8.6 Fungal diseases of post-harvest fruit

1.8.6.1 Crown rot

The disease occurs at optimum temperature >16 to 40°C, and relative humidity >86% (viable under high temperature and low humidities).

1.8.6.2 Finger rot

Optimum temperatures of 27-29°C are congenial to finger rot to occur.

1.8.6.3 Anthracnose (peel blemish)

Peel blemish occurs with optimum temperatures of 27-30°C, and 96-100% humidity. No growth is observed at temperature <15°C and relative humidity <92%.

For precise definition of temperature, rainfall, humidity threshold conditions for occurrence of pests and diseases, quantitative information on the weather and organism growth relationships during the various growth phases of both the organism and the banana plant are needed. The present level of available information on these aspects is inadequate and a few illustrative examples of such information reported earlier in respect of banana crop had been cited by Sastry (1988). Investigations under both controlled and natural field conditions will provide the required data base for development of forecasting models and spray schedules. This important aspect needs priority attention.

1.9 CONCLUSION

Threshold values are available in respect of banana crop on some aspects of operational management, e.g., information needed for agroclimatic zoning of banana growing areas in relation to rainfall and temperature, irrigation needs, evapotranspiration, bunch initiation, fruit ripening, sigatoka disease, etc. However, the definitions attempted above are representative values put together from research reports which are limited in number. More research information is needed to refine and redefine these thresholds which are extremely useful and essential for operational management of the crop. To make them readily useable, it is necessary to reanalyse climatological data with specific reference to the threshold values mentioned above with reference to the phenology of banana crop. The tables and maps that might provide agrometeorological information on banana crop using the threshold values and relevant to CARS-FOOD programme are listed in the Appendix. This should not be considered as an exhaustive list but indicative of the type of information that could be utilized by banana growers for operational purposes.
I.10 APPENDIX (suggested tables and maps)

List of maps and tables useful for agricultural operations in banana crop. Crop growth phases can be indicated along with each table for interpretation as response varies with growth phase.

CROP PARAMETERS

- List of major banana varieties grown in a country, (region-wise if information is available)
- Normal months of planting
- Irrigated or rainfed
- Crop coefficients for different growth phases
- Duration from planting to harvest for first crop
- Duration from ratoon to harvest for ratoon crop
- Time of floral initiation
- Time of bunch initiation
- Date of harvest
- Yield
- Major insects/pests with dates of incidence

CLIMATIC PARAMETERS

Regional scale analysis

- Areas receiving 100 mm/month or 25 mm/week in all 12 months
- Areas with mean air temperature between 25-30°C
- Areas with cool winters (mean minimum temperature < 10°C)
- Areas with hot summers (mean maximum temperature > 40°C)
- Areas of frost occurrence showing frequency and duration
- Areas with mean minimum temperature between 10-15°C
- Areas with rainfall < 100 mm/month for three consecutive months
- Tracks of cyclones
- Areas visited by frequent squalls
- Areas with light intensity < 20,000 lux

Single station analysis

- Weeks with rainfall > 25 mm/week
- Weeks with mean air temperature between 25-30°C
- Weeks with mean minimum temperature < 10°C
- Weeks with mean maximum temperature < 42°C
- Weeks of frost occurrence
- Weeks with mean minimum temperature > 15.5°C
- Weeks with mean minimum temperature between 10-15°C
- Weeks with monthly mean minimum temperature > 15 and < 40°C
- Weekly pan evaporation
- Weekly potential evapotranspiration
- Weekly estimated water requirements (PET x crop coefficient)
- Weeks with rainfall < 25 mm/week
- Weeks with wind speeds > 50 kmph with probabilities
Weeks with wind speeds > 90kmph with probabilities
Weeks of energy gained by crop (pan evaporation > net radiation)
Weeks favourable for leaf production (> 8°C and < 33°C)
Weeks favourable for leaf expansion (> 12°C and < 33°C)
Weeks optimum for leaf production/expansion (31.5°C)
Weeks optimum for fruit growth (25-29°C)
Monthly Ts index values (see text for formula)
Probable weeks of water logging for 48, 72 and 96 hours

(Significance of the threshold values is given in the text)
I.11 BIBLIOGRAPHY


II. REPORT ON COTTON CROP

Definition of Agrometeorological Information on Cotton Crop

by

Dr B.C. Biswas (India)
(Rapporteur on Definition of Agrometeorological Information Required for Cotton Crop)
DEFINITION OF AGROMETEOROLOGICAL INFORMATION FOR COTTON CROP

II.1 INTRODUCTION

Cotton crop is grown under widely varying climatic conditions both as a rainfed and irrigated crop all over the world. The important meteorological factors affecting the growth, development and yield of this crop are, rainfall, air and soil temperatures, and soil moisture. Weather also affects the incidence of pests and diseases of this crop. Many agricultural operations (weeding, spraying, fertilizer application, harvesting) are significantly dependent on weather factors. Information on threshold values for these elements assist crop management decisions. In the pages to follow, the different aspects of crop-weather interactions in cotton crop are reviewed with particular reference to critical values of weather elements affecting its growth, development and yield.

II.2 THE COTTON PLANT - NOMENCLATURE

The cotton plant belongs to the genus Gossypium which is a member of the natural order Malvales, family Malvaceae, series Hibisceae of the dicotyledons group of plants. The cultivated cotton in general is found in four of the following species of Gossypium:

Diploid Old World Cottons : G. arboreum; G. herbaciun
Tetraploid New World Cottons : G. hirustum; G. barbadense

II.2.1 Brief description of the plant

The cotton is a perennial plant which may reach heights of 0.6 to 1.8 m. It has a tap root whose size and depth vary according to soil type, soil temperature and soil moisture, and the variety of the crop. The tap root penetrates up to 2-3 m depth and the latent roots extend radially up to a distance of 2 m. Active root zone for moisture extraction is normally confined to 60-90 cm depth. Roe (1950) suggested that moisture content in the 0-30 cm depth could be used as a measure to schedule irrigation up to the flowering stage of the crop, and that in the 0-60 cm layer for planning irrigation later in the cropping season.

The stem is erect and carries two types of branches: (i) the vegetative branches which are more vertical and ascending; (ii) the fruiting branches which are nearly horizontal or inclined upwards at an angle of 45-90 degrees from the vertical. The mainstem produces a series of nodes. A sketch of the branching habit of the cotton plant given by Munro (1987) is shown in Figure II.1.
Figure II.1. Branching habit of the cotton plant. (Reproduced from Munro, 1987)
The leaves are spirally arranged on the mainstem and the vegetative branches, cordate shaped and palmatifide. Stomata are observed on both sides of the leaf, being more numerous on the underside of the leaf. The flower bud first becomes visible as a small green cone, closely pressed to the fruiting branch. The flowers are terminal and solitary, and the fruits are known as "bolls" containing 8-10 seeds. The node number of the first fruiting branch (NFB) and the number of nodes produced on the mainstem before fruiting are a special and significant characteristic of the cotton plant. All cultivated cotton bolls bear long fibres named "lint".

II.2.2 Origin of cotton

Cotton fabrics have been found dating back to 3500 B.C. but their use in the civilization of Mesopotamia, Babylon and Egypt is not recorded until about 500 B.C. (Hutchinson, et al., 1947). It finds mention in the Rig Veda, the oldest scripture of the Hindus.

The earliest known coarse cotton fabrics in the Old World were made of cotton produced from a plant closely related to G. arboreum type, belonging to the Indus Valley Civilization dating back to around 3000 B.C. (Gulati and Turner, 1928). Stebbins (1947) examined fruits, foliar parts and fibre of cottons taken from archaeological contexts, dating to about 2500 to 1750 B.C., in Peru. The impetus for the utilization of cotton in the area seems to have been the need for cordage for fishing lines and nets.

A diploid species possible G. arboreum might have been domesticated in Nubia (Ciba-Geigy, 1972, quoted by Munro, 1987) for the seeds as a nutritious feed for domesticated animals. Hutchinson, et al., (1947) opined that the presence of seed fibres was the chief impetus for the domestication of G. herbaceum in the Old World but hypothesized that spinnable fibre represented a mutant, presumably rare, phenotype in a wild, or perhaps early domesticated form of the cotton. These workers concluded further that the New World tetraploid cottons evolved under domestication after the introduction of a cultivated one.

Evidence indicates that cotton grows as a wild plant in Southern Africa and possibly also in the Sahel of North Africa and most likely domesticated species arose from these wild plants. Cotton was used in Mexico in some form between 4000 and 3000 B.C. Linted cotton species were being produced between 4000 and 3000 B.C. as diploids in India and tetraploids in Mexico and Peru. (Smith, 1968, quoted by Munro, 1987). The history of cotton production and its distribution has been dealt extensively by Munro (1987).

II.2.3 The spread of cotton

It is known that Alexander the Great took cotton from India and introduced it to Macedonia and the Western World. Evidence for the existence of cotton industry is found in the Merotic Empire of the Sudan and dates to about 400 B.C. (Hutchinson, 1962). The growing of cotton in the Eastern Mediterranean followed the introduction of cotton goods. The crop became established in lower Egypt and in the Levant. Cotton (most likely G. herbaceum) was introduced into Spain by Moors in 712 A.D. In Italy, during the Renaissance period, cotton fabrics developed to the point of promoting style in clothing. The state of Venice forthwith became the leading commercial centre of the Mediterranean, depending largely upon cotton goods from India. From Venice, cotton found markets as
far away as northern Europe. Cotton spread to China prior to the 13th century probably from India, and made its appearance in England first in 1298 A.D. Cotton has been grown in Egypt since about the 14th century, but it does not appear to have been a crop of any significance; Egypt was importing cotton from Syria and Cyprus.

Cotton became a crop of local importance in the south-eastern U.S. by the middle of the 18th century. The early variety, known as "Georgia Green Seed" was probably of Mexican origin (Hutchinson, et al., 1947). In this century the imports of cotton goods from India created such demand in Europe that much of the spinning and weaving industry in Britain was diverted to the production of cotton goods (Trevelyon, 1942). New varieties of American origin had already been developed in Egypt, while American Upland varieties were being grown in Turkey, Greece and Africa south of Sahara.

The first "day neutral" variety was developed in South Carolina and Georgia, in the early 19th century, known today as Egyptian cotton (Balls, 1912). Egyptian cotton later gave rise, through further hybridization, to the Pima cotton of the South-western U.S. and to the limbless cultivars of G. barbadens grown in the former USSR. Varieties from USA have now been spread to all parts of Central and South America, Afghanistan, Australia, Indonesia and Thailand and to many other countries. Figure II.2 gives the areas of the world where cotton is grown at the present day.

II.2.4 Production

Generally cotton is categorized as a tropical plant. Presently, about 65% of the world production is contributed by regions lying north of latitude 30°N where the crop can be grown only in the summer months; it ripens in September to November in these regions. Summers being too short for growing cotton, early maturing varieties are grown in the areas north of 40°N. The Southern hemisphere contributes about 10% of the total production, with ripening in May to July. The remaining 25% is produced in the northern tropical regions up to 30°N, mostly ripening in December to February. Due to the occurrence of frost, temperature rather than rainfall is the predominant factor that limits growth of cotton outside the tropical belt. Irrigated cotton especially in the tropics may be grown at any time of the year depending on the availability of water supply, which might be the limiting factor in non-active monsoon years in the countries visited by the monsoons.

Cotton production of the world had increased from 6 million tonnes in 1938-39 to over 18 million tonnes in 1990 (Figure II.3) and is around 20 million tonnes in 1995. Three countries (the People's Republic of China, the United States of America and the former Union of Soviet Socialist Republic) produce more than half of the world's cotton crop. The percentage of cotton produced in the different continents is given in Figure II.4.
Figure II.2. Cotton growing areas of the world. (Reproduced from Munro, 1987)
Figure II.3. World production of cotton since 1980

Figure II.4. Production of cotton in the different continents

LEGEND:
- - - AFRICA (7.49%)
+++ ASIA (46.52%)
\(\Rightarrow\) N. AMERICA (19.05%)
- - - S. AMERICA (7.86%)
--- EUROPE (18.84%)
| | | OCENIA (17.22%)
INCLUDING U.S.S.R.
Cotton is extensively cultivated in India and Pakistan. It has shown a steady increase since the 1950s. Brazil, Egypt, Mexico and Turkey have increased their production significantly during the last 20 years. In Africa, the flourishing industries in Mozambique, Nigeria, Tanzania, Uganda and Zaire have declined over the last two decades while those in Chad, Ivory Coast, Mali, South Africa and Zimbabwe have become major producers.

There has been a general increase in production in the Middle-east and Europe, up to about 1975, and steadied since then at that level. While Greece and Israel have continued to expand, Iran, Spain and the Sudan showed some decline in production. In South America, Paraguay recorded a very significant increase in production in the last ten years. The production of cotton in some of the major cotton producing countries is given in Figure II.5.

Figure II.5. Cotton production in selected countries
Cotton production has been revolutionized by the new insecticides introduced since the 2nd World War. It is now possible to grow cotton successfully wherever the climate is suitable, by controlling the insect pests, where production was previously a failure due to disease/pest problems. This is not to say that pest problems have all been solved.

Cotton production is also expressed in terms of staple length (ICAC, 1983). Extra-long staple (over 35 m) as grown in Israel, Morocco, the Nile Delta, Sudan and U.S.A. Under rainfed conditions, the longest and finest cotton is grown in the windward and leeward islands of the West Indies. Long staple cotton (over 28 mm) is being produced in Egypt, India, Uganda and the West Indies in recent years.

II.3 PHENOLOGY AND CROP COEFFICIENTS FOR COTTON CROP

With regard to cotton crop no clear cut demarcation could be made in crop growth periods since there is an overlap between vegetative growth and development of pheno phases. Vegetative growth continues during both flowering and boll formation. Flowering continues during boll formation. However, the following growth stages mentioned by Doorenbos and Kassam (1979) in connection with estimation of evapotranspiration and water requirements of the cotton crop, are useful:

<table>
<thead>
<tr>
<th>Growth stage</th>
<th>Average duration (days)</th>
<th>Growth stage</th>
<th>Average duration (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Establishment</td>
<td>15-25</td>
<td>Yield formation</td>
<td>30-40</td>
</tr>
<tr>
<td>Vegetative</td>
<td>25-35</td>
<td>Ripening</td>
<td>15-20</td>
</tr>
<tr>
<td>Flowering</td>
<td>60-70</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

For determination of ET and water requirements, the crop coefficients suggested by them are:

<table>
<thead>
<tr>
<th>Seedling stage</th>
<th>0.40 - 0.50</th>
<th>Late season</th>
<th>0.80 - 0.90</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vegetative</td>
<td>0.70 - 0.80</td>
<td>At harvest</td>
<td>0.65 - 0.70</td>
</tr>
<tr>
<td>Mid season</td>
<td>1.05 - 1.25</td>
<td>Total growing season</td>
<td>0.80 - 0.90</td>
</tr>
</tbody>
</table>

Phenophases are variety specific and also to some extent location specific. For north western regions of India, the following phenophases and crop coefficients had been used (Sahu and Sastry, 1992a) for working out water requirements of the crop.
For illustration, a phenology diagram in relation to different planting dates and for Upland and Pima cotton (Kittock, et al., 1981) is shown in Figure II.6.

Figure II.6. Planting dates and phenology of cotton cultivars. (Reproduced from Kittock, et al., 1981)
II.4 IMPACT OF CLIMATIC FACTORS ON COTTON

An ecological balance always exists in some form between the natural vegetation and the climate. Natural variations in climate influence the cotton crop like for any other crops, during its different growth phases and development. Apart from the genotype characteristics, the growth, development and yield are directly attributable to changes in rainfall, temperature, humidity, solar radiation and soil type.

Cotton grows well on a wide range of soil types which provide adequate drainage and unrestricted rooting depth. It cannot stand water logging. Any reduction in rooting depth is reflected in the growth of the above-ground parts and a consequent limitation on the yield potential.

II.4.1 General effects of climate on growth of cotton crop, including crop planning

Incessant rains or a long spell of dry weather may prevent the sowing of the crop at the proper time, hinder seed germination, or retard crop growth. Heavy rains, continuous high winds or excessive drought at flowering and fruiting time may cause heavy shedding of buds and young bolls, thereby causing drastic reduction in crop yield. Untimely rains with heavy humid weather during the later stages of the cotton season might spoil the produce, lower the fibre quality, or promote the attack of pests and diseases. An early frost may kill the plants prematurely. While night temperatures affect boll maturation periods, soil temperature and moisture play an important role in development of seed borne diseases. Thus the success or failure of the cotton crop at a place is intimately related with the prevailing weather conditions (ICCC, 1960).

The climatic requirements for the successful cultivation of cotton are:

1. A mean annual temperature of over 16°C.
2. An annual rainfall of at least 50 cm with favourable distribution.
3. Abundant sunshine during the period of boll maturation and harvesting of the produce.
4. A frostless season of 180 to 240 days in the year.

II.4.1.1 Time of sowing

In areas where both water supply and favourable temperature conditions for growth of cotton are assured, cotton can be planted at any time of the year. In the sub-tropics, sowing is restricted to non-winter period of the year so that crop matures before onset of low or below freezing conditions. Where temperature is unfavourable due to long frost periods, short duration varieties are grown during summer. Sowing date also needs to be adjusted with respect to favourable duration of growth period so that probable periods of pest/disease occurrence could be avoided.

Frere and Popov (1979) suggested a rainfall of 25 mm/week after onset of rains as the optimum sowing time for rainfed regions. In the Gujarat region of western India, sowing dates between June 25 to July 29 fall in this category (Sahu and Sastry, 1992a).
II.4.2 Rainfall

Rainfall is the prime meteorological factor of growing rainfed cotton especially in the tropics. As mentioned earlier, the sowing time is much dependent on onset of rains in the monsoon regions. Well distributed rainfall of 50 cm in one growing season or 100 cm per year where cotton crop can be raised throughout the year, are considered adequate for cotton. A relatively dry period and good sunshine of at least four hours per day at the end of the season after boll opening ensures not only good seasonal conditions for ripening but also freedom from boll diseases and pests.

Manning (1951, 1956) made study of rainfall and its bearing on cotton production with particular reference to Africa. He estimated that the moisture holding capacity of the soil was sufficient on an average to allow the cotton plant to withstand three weeks without rain and chose a three-week period as the basis for his calculations. He computed moving totals and standard errors for three-week periods and the 1:1 confidence limits. Typical rainfall chart (Thorp, 1973) is shown in Figure II.7.

Figure II.7. Confidence limits of expected rainfall (---) and water requirements (—) of cotton, Uganda. (Reproduced from Thorp, 1973)
This could be interpreted to say that rainfall in about two out of four years will be between the two limits (broken lines in figure), and one year in four will fall below the lower limit and may exceed the upper limit once in four years. Distance between the lines is a measure of rainfall variability.

By superimposing water requirements of cotton crop on the rainfall chart, various sowing dates are tested for availability of adequate rainfall for growth of the crop; probability of dry weather occurrence needed for boll ripening can also be estimated from these charts. Several workers in Africa followed this technique and computer programmes for these computations had been developed (Walker and Rijks, 1967, Thorp, 1975).

II.4.2.1 Rainfall probability

Assured rainfall is an important factor in rainfed farming. Biswas and Khambele (1979) and Sarker, et al., (1982) calculated weekly assured rainfall by fitting incomplete gamma distribution model to weekly rainfall totals of about 1,000 stations spread over cotton growing areas of India. As an illustration, weekly assured rainfall at different probability levels at Akola, a cotton growing station in India, is shown in Figure II.8. Probability of water stress periods and the need for supplementary irrigation can be estimated from such information.

II.4.2.2 Length of growing period

For estimating length of growing period of crops, Cochemé and Franquin (1967) estimated ‘water availability’ periods in term of various fractions of potential evapotranspiration. Hargreaves (1971) introduced a moisture availability index (MAI) defined as the ratio of dependable rainfall at 75% probability to the potential evapotranspiration at a place. He computed crop growing periods on the basis of MAI < 0.34 with an emphasis on how continuous and long is the period during which MAI is equal to or greater than this value. Biswas (1982) computed weekly MAI (instead of for monthly intervals), for different risk levels and MAI limits of 0.3 and 0.7 have been used depending on the crop growth stage. Being location specific, no threshold values can be fixed for rainfall amounts in relation to cotton growth but the assured rainfall and moisture availability maps can be utilized to interpret these factors in terms of crop water requirements, evaporative demand and water availability periods, for the crop species grown in the region.

II.4.3 Floods and water logging

Severe flooding caused by the heavy rainfall associated with cyclonic storms occurs where these storms cross the coast. Heavy rainfall with an intensity of more than 100 mm in 24 hours, cause flooding and water logging in cotton fields, damaging standing crops.

Water logging is detrimental to growth of cotton crop due to poor aeration in the root zone. It has been observed that the effect of water logging becomes evident after about a week’s time when photosynthetic rates drastically decrease by about 85%. Information on frequencies and duration of water logged periods on weekly basis in respect of cotton growing regions would be pertinent for remedial action.
Figure II.8. Weekly assured rainfall probabilities, Akola (India)
II.4.4 Dew

The part played by dew in cotton cultivation is two-fold. The dew deposited on the leaf surfaces in the morning delays the rise in leaf temperature and thus reduces the rate of evapotranspiration (Long, 1958). Secondly, it provides water for direct plant use. If the cotton growing areas happen to be dry in winter, as is the case in Egypt, western India, Pakistan, etc., the contribution of dew is of considerable importance. In such areas the amount of dew deposition varies from 0.25 to 0.40 mm per night.

II.4.5 Hail

Hailstorms cause severe damage to standing crops by causing mechanical injury to plants. The effect of hail on young cotton plant or ratoon which has not yet fully developed, leads to severe shedding of leaves and total loss of the crop. Mapping of hail storm zones with frequency of occurrence would help in crop planning.

II.4.6 Frost

Frost is perhaps the most injurious thermal hazard, as far as cotton is concerned. Plants with large cells in their tissues are known to be most susceptible to damage by frost (Lemitt, 1956). Cotton can therefore flourish only in frost-free areas, for most parts of the year, generally between latitudes 30°N and 30°S. Similarly, altitude also limits the growth of cotton, because of the occurrence of frost. From meteorological point of view, frost occurs when the air temperature falls below freezing point 0°C. Frost probability tables with reference to phenophases of cotton crop and accurate forecasting on the occurrence of frost are of great significance for cotton crop planning and operational management.

II.5 TEMPERATURE AND GROWTH OF COTTON

Temperature serves as a primary factor controlling the growth of cotton and developments, such as appearance of leaf, flower, node, etc., and the time interval between anthesis and fruit maturation (Baker, 1965, Baker, et al., 1972). Photosynthetic rates are known to be less sensitive to temperature than rate of growth and development (Baker, et al., 1983). The case study reported by Dastur (1950) is an illustrative example of how small temperature variations influence different developmental stages in cotton after bud appearance until boll production.

II.5.1 Seed germination and emergence

For seed germination, a minimum daily temperature or a minimum soil temperature of 16°C had been suggested by Dastur (1950). At soil temperatures of 21°C and above, Balls (1953) reported 60-70% seed germination. Erickson and Michelini (1957) observed that cotton germination is severely affected when the temperature falls below 14°C. Tharp (1960) considered that air temperature below 16°C is not conducive to the growth of cotton plant. In the USA, the sowing date for cotton was observed to shift towards north with advancing spring, generally following the movement of the 16°C isotherm.

From seed germination tests, Balls (1953) derived a value of 32°C for optimum germination. However, Tharp (1960) arrived at an optimum soil temperature of 34°C for earliest seed germination and rapid seed growth. Pursglove (1968) gave the optimum
temperature for germination as 34°C. As an upper threshold, the limit of temperature up to which cotton crop can survive had been put at 37.5°C from studies in Egypt (Ballis, 1953). Sikka and Dastur (1960) stated that Asiatic cottons under good moisture conditions could stand temperature even as high as 43-46°C.

From the above, it may be inferred that lower and upper thresholds for seed germination are 16°C and 45°C respectively with an optimum in the range 30 to 35°C.

II.5.2 Vegetative growth

Seedling growth had been found to be optimum between 24 to 29°C (Pursglove, 1968). For vegetative growth, Sikka and Dastur (1960) suggested an optimum temperature of 21 to 27°C.

In case of Upland cotton in the USA, Johnson (1962) stated that "other conditions being satisfactory, the most favourable day temperature for the optimum growth of cotton is 32°C, with a corresponding warm night". Pursglove (1968) also agreed with this value. It had also been noted that time taken to reach five expandable leaves (early growth) varied between 22 days at 32°C and 45 days at 22°C. A daily maximum temperature >20°C with a desirable value of 30°C was suggested by Mauney (1966). Powell (1969) showed that continuous exposure at 32.2°C for 11 hours does not have any adverse effect on the growth of cotton.

II.5.3 Flowering

Varieties differ not only in respect of floral initiation, but also with regard to peak period of flowering, total flower production per plant, and shedding of squares and flowers.

It generally takes about two to three months from the formation of the first flower to the bursting of the boll and this is marked by two developmental stages:

Square period: The time taken by a bud to open into a flower.

Boll period: The time taken by an open flower to develop into an open boll.

In order to have a precise estimate of the harvesting time, it is necessary to record the square period and the boll period under different conditions of climate in relation to sowing time.

II.5.4 Bud initiation

The date of appearance of first flower bud on the cotton plant can be regarded as an important physiological character, indicating the probable time of maturity. A number of factors besides sowing date, such as temperature, node number of the first fruiting point (NFB), and water supply, may have to be considered in forecasting likely time of arrival of the crop in market.

For appearance of the first flower, under comparatively cool day time temperature (28°C) with a 12-hour day, an Upland variety may take 65-70 days from planting, while the same variety under warmer conditions (33°C) may take about 45 days as observed in
Malawi and Uganda (Munro, 1987). An average period of 55 days has been suggested by him for the Upland variety.

II.5.5 Night temperatures and growth

Lower night temperature (above freezing) affect appearance of the node on the first fruiting branch (NFB), length of growing season, boll maturation period, fibre length, seed quality, cellulose production, etc. On the other hand, the adverse effects of high night temperatures had been noted in Arizona (Fisher, 1973). If high temperatures occur when the first flowers are due to open, the absence of early bolls allows vegetative development further, resulting in a tendency to rank growth which is found in areas or seasons where the minimum temperature exceed 24°C.

Higher night temperatures also progressively delay the appearance of the NFB. At night temperatures of 25°C, day temperatures were found to have little effect. But at high night temperatures, high day time temperatures raises the NFB and lowers it when the night temperatures are lower. Similar results have been reported in Australia by Low, et al., (1969).

The effect of night temperatures on boll period, cellulose production and micronaire values (fibre quality), were investigated by Gipson and Ray (1970). Plants were exposed to normal day time environment and night temperatures were imposed for eight hours. There was a marked decrease in all the three parameters when night temperatures were decreased to 15°C, though varieties exhibited difference in the magnitude of decrease (Table II.1).

Table II.1. Effect of temperature on boll maturation periods, cellulose production and micronaire value (seasonal means)

(a) Boll maturation period

<table>
<thead>
<tr>
<th>Night temp. (°C)</th>
<th>Variety</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Acala 1517 BR-2</td>
</tr>
<tr>
<td>Number of days of boll period</td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>50.5</td>
</tr>
<tr>
<td>21</td>
<td>66.2</td>
</tr>
<tr>
<td>15</td>
<td>87.3</td>
</tr>
<tr>
<td>11</td>
<td>95.9</td>
</tr>
</tbody>
</table>

Source: Gipson and Ray (1970)

Regressions between boll periods and night temperatures gave correlations of -0.96 to -0.99.
(b) Rate of cellulose production

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Acala</th>
<th>Stoneville</th>
<th>Lankart</th>
<th>Stripper</th>
<th>CA 491</th>
</tr>
</thead>
<tbody>
<tr>
<td>27</td>
<td>45.4</td>
<td>31.6</td>
<td>49.9</td>
<td>30.1</td>
<td>27.6</td>
</tr>
<tr>
<td>21</td>
<td>39.8</td>
<td>30.4</td>
<td>31.9</td>
<td>30.8</td>
<td>27.1</td>
</tr>
<tr>
<td>15</td>
<td>22.6</td>
<td>19.4</td>
<td>24.6</td>
<td>22.6</td>
<td>19.4</td>
</tr>
<tr>
<td>11</td>
<td>18.8</td>
<td>11.5</td>
<td>22.4</td>
<td>17.7</td>
<td>14.4</td>
</tr>
</tbody>
</table>

Reduction in night temperatures below 15°C resulted in a significant decrease in rate of cellulose production.

(c) Micronaire value

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Acala</th>
<th>Stoneville</th>
<th>Lankart</th>
<th>Stripper</th>
<th>CA 491</th>
</tr>
</thead>
<tbody>
<tr>
<td>27</td>
<td>4.08</td>
<td>4.28</td>
<td>4.44</td>
<td>5.33</td>
<td>3.88</td>
</tr>
<tr>
<td>21</td>
<td>4.08</td>
<td>3.89</td>
<td>3.71</td>
<td>5.70</td>
<td>3.46</td>
</tr>
<tr>
<td>15</td>
<td>3.13</td>
<td>2.94</td>
<td>3.65</td>
<td>4.57</td>
<td>3.37</td>
</tr>
<tr>
<td>11</td>
<td>2.51</td>
<td>2.44</td>
<td>3.08</td>
<td>3.36</td>
<td>2.85</td>
</tr>
</tbody>
</table>

The effect of night temperature on oil accumulation was curvilinear (Figure II.9). Night temperatures in the range 17-22°C yielded highest oil content. Results ($R^2$) also showed that the different cultivars have different sensitivity to night temperatures in oil accumulation when temperatures are lowered. Similar relations if locally developed would provide useful definitions for estimation of oil accumulation for different thermal environments under natural field environments.
Figure II.9. Seed oil content as influenced by night temperature. (Reproduced from Gipson and Ray, 1970)

II.5.6 Day/night temperatures

It is evident that diurnal variation in temperature during bud initiation to boll set and opening period is an important factor in growth and development of cotton crop. Varieties differ not only in respect of earliness in the initiation of flowering, but also with regard to peak period of flowering, total flower production per plant, and shedding of squares and flowers.

This has been studied by several researchers using maximum and minimum temperatures in field grown crops and in growth chambers using day/night temperatures under controlled conditions.

A few examples are illustrated below which throw light on the different aspects of the effect of day/night temperatures and differences in varietal response that are encountered at field level in agricultural operations such as prediction of boll maturity and ripening periods for harvest, boll retention/shedding, and modelling crop growth and development in cotton plant.
II.5.7 Leaf area

Optimum growth for leaf area was determined by Hesketh and Low (1968) as 33/28°C and for dry weight accumulation, the range was 30/25 to 33/28°C. Cotton plants exposed to moderately low temperature of 24/19°C after germination for two-three weeks will have 30-50% less leaf area than those growing at 33/28°C (Moraghan, et al., 1968).

5.8 Node of the first fruiting branch (NFB)

Both maximum and minimum temperatures are known to affect the NFB (Mauney, 1966); night temperatures in the range 20 to 22°C lower the NFB, counting up the stem from the cotyledons (Table II.2).

Table II.2. Interaction of day and night temperature on node of floral initiation:

<table>
<thead>
<tr>
<th>Night temperature °C</th>
<th>Day temperature (°C) (14 hours per day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 hrs/day</td>
<td>22</td>
</tr>
<tr>
<td>32</td>
<td>13.0</td>
</tr>
<tr>
<td>28</td>
<td>8.7</td>
</tr>
<tr>
<td>25</td>
<td>9.1</td>
</tr>
<tr>
<td>22</td>
<td>9.0</td>
</tr>
<tr>
<td>20</td>
<td>8.9</td>
</tr>
</tbody>
</table>

Source: Mauney (1966)

II.5.9 Flowering

Mean daily day/night temperatures higher than 20/12°C were suggested as essential (Eaton 1955, Carns and Mauney 1968) for squaring and flowering when maximum temperature exceeds 40°C or the minimum exceeds 27°C flowering tends to be inhibited.

When plants were subjected to day/night temperatures ranging from 18/13 to 36/31°C at intervals of 3°C, it was noted that the reduction of night temperatures to 13°C delayed squaring in the plants compared to those subjected to 33/19 and 33/28°C (high night temperatures (Moraghan, et al., 1968). He also obtained results on the effect of temperature and photoperiod combinations. Long days and high temperature before floral initiation were found to delay flowering in cotton lowering the yields. Upland cotton produced squares at moderate temperatures of 20-24°C irrespective of length of the day. At high temperature of 30-34°C plants grown under short day conditions produced squares while plants grown under long day conditions did not.
Temperatures below 20°C and above 45°C might result in pollen sterility and incomplete fertilization (Sowell and Rouse, 1956). Data on G. hirsutum (Ehlig and Le Mert, 1973) showed that three weeks after periods when the maximum temperature exceeded 42°C reduced the number of flowers per meter on row length.

Reddy, et.al., (1992) observed that optimum temperature for maximum growth rate of leaves, mainstem, and fruiting branch was 30/22°C; and development rate, as depicted by number of mainstem nodes produced, were sensitive to day/night temperature of the order of 40/32°C. The number of fruiting branches did not increase above 30/22°C. Most flower buds on plants grown at 35/25°C and all flower buds (squares) from plants grown at 40/32°C abscised. Plants grown in the high temperature regimes lose their reproductive capacity to a greater extent than they lose their ability to produce biomass. The impact of temperature on plant height and mainstem nodes is given in Figure II.10.

II.5.10 Boll development and production

Temperatures in the range 27 - 32°C were reported to be desirable during boll development and maturation (Mauney, 1974). Maturation ranges from 40-90 days. Optimum for boll production was observed to change with light intensity. At day/night temperatures of 33/28°C, 370 langley/day was sufficient to produce optimum boll production, while at 30/25°C 510 langley/day were required.

II.5.11 Mean daily temperatures and boll development

At mean daily temperatures of 26-24, 23-19, and 18-16°C Guo (1985) noted that 50-60, 60-70 and >80 days respectively were required for boll development of cotton in China. For elongation of fibre cells and thickening of secondary walls, the optimum temperature required was 25°C. With mean daily temperatures for boll development at 20-25°C, 85 per cent of seeds attained maturity while the percentage rapidly decreased below temperatures <25°C.

II.5.12 Boll period

A decrease either in day or night temperature resulted in slower boll development, increasing the boll formation period. In short time required for formation of flowers or opening up to of bolls decreased steadily with increase in temperature (Fig. II.11). The lower limit of temperature for formation of bolls as reported by Hesketh and Low (1968) was 18/13°C, i.e. 15°C (mean daily temperature).

II.5.13 Temperature and boll retention

Boll retention was found to be low around 29.4°C (Powell, 1969) but interruption of this high temperature with cooler temperatures of the order of 21°C resulted in a greatly increased boll retention. It was noted that short period temperature changes under natural field environments could be used for stopping the shedding of bolls or its retention. On the other hand, no direct relationship was observed between boll retention and high
maximum/minimum temperatures or high relative humidity by Ehlig and Le Mert (1973). However, they observed that two successive days with temperatures above 45°C resulted in heavy boll shedding. They concluded that in the absence of boll load on the plant, boll retention would be high in the range normally required for boll production irrespective of actual values of temperature and humidity experienced by the cotton plant. They further concluded that boll retention is more dependent on fruit load on the plant rather than on temperature or relative humidity.

Sequential temperature of 45°C or more for two or three consecutive days may be defined as upper threshold, 18°C as the lower threshold, optimum as 27-32°C and daytime and night temperature range as 20-24 for boll production and retention.

II.5.14 Temperature and fruit set

It had been observed that plants grown at 32°C night temperature inhibit fruit setting. Length of boll period is inversely related to temperature. Maximum vegetative growth rates (dry weight basis) occurred at 36/31°C. Day and night temperatures of the order of 30/25°C and 32/28°C did not result in maximum boll setting because severe boll shedding was caused at these temperatures (Hesketh and Low, 1968).

An optimum day/night temperature of 27/22°C (Lomas, et al., 1977) was suggested for boll weight. Maximum temperatures greater than 38°C decreased yield considerably.

Effect of temperature on germination, growth and development in cotton summarised from literature by Lomas, et al., (1977) is reproduced in Figure II.12.

Generalised temperature-yield response curve in cotton based on 10 years of field observations, and analysed using orthogonal functions derived by Lomas, et al., (1977) is shown in Figure II.13. The effect of 1°C change in temperature on the projected changes in yield during the growth period of cotton is brought out in the figure.
Figure II.10. Effect of temperature on cotton; (a) plant height (b) main stem nodes

(Reproduced from Reddy, et. al., 1992)
Figure II.11. Days from (a) square to flower, (b) flower to boll open and (c) sum of one time intervals

(Hasketh and Low, 1968)
Figure II.12. Temperature effect on duration of; (1) germination, (2) growth, (3) flowering, (4) boll period

(Reproduced from Lomas, et al., 1977)

Figure II.13. General response curve of cotton to temperature (1) Early growth, (2) Flowering, (3) Boll development (4) Ripening

(Reproduced from Lomas, et al., 1977)
II.5.15 Growing degree days

A mean daily temperature of 10°C was used by Mc.Mahon and Low (1972) for calculating growing degree days and Wallach, et al., (1978) used this for defining a "physiological day". Malm and Kerby (1981) used a base temperature of 12.8°C for the same purpose. Temperature-growth curves in cotton derived by Munro (1971) indicated a base temperature of 14°C as a suitable temperature because growth definitely slowed down at and below 14°C. These results show that 12°C can be defined as a "base temperature" for working out degree days for cotton crop.

II.5.15.1 Prediction model for boll opening using degree days

Management decisions such as scheduling of harvest, defoliation or irrigation operations in cotton crop depend on the time of boll opening. It would be advantageous, therefore, to know this event in advance. Wallach and Kletter (1981) developed a prediction model using counts of large bolls (bolls with fresh weight greater than 10 g, and temperature during boll development in the form of degree days. A base temperature of 12°C was used and degree days were worked out separately for day and night temperatures, with an upper threshold of 30°C for maximum temperatures.

Accumulation of 560 day degrees was used to determine the time of opening of large bolls. However, this value is location and cultivar specific. It is desirable to use experimentally determined threshold values at each site before applying the model in other areas.

II.5.16 Temperature and fibre quality

A decrease in minimum temperature increased duration of fibre elongation and dry matter accumulation in four Gossypium species of cotton tested by Thaker, et al., (1989), but lint index (dry weight per seed) increased with an increase in minimum temperature. Hesketh and Low (1968) derived a quadratic regression between fibre strength and different day/night temperatures in four species of cotton (Fig. II.14) which served as an example of the effect of temperature on fibre quality.

II.5.17 Temperature and chilling injury

Chilling injury is the damage brought about by near freezing low temperatures in cotton plants at various growth stages (Table II.3) Chilling causes a disruption of metabolic activity leading to death of the plants. The stage of germination had been known to be important in determining the extent of injury (e.g. chilling of pre-emergence seedlings can cause delay in maturity). Prolonged exposure to chill weather brings about severe damage at pre-squaring and squaring stages.
Figure II.14. Effect of temperature on fibre strength

(Hesketh and Low, 1968)
Table II.3

Effect of chilling of cotton plants at different growth stages twenty days after treatment. (Injury measured on scale 0 for control and 5 for complete kill)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Growth stage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>seedling</td>
</tr>
<tr>
<td>Control</td>
<td>0</td>
</tr>
<tr>
<td>7°C 78%R.H.</td>
<td>96 hrs</td>
</tr>
<tr>
<td></td>
<td>144 hrs</td>
</tr>
<tr>
<td>13°C 50%R.H.</td>
<td>96 hrs</td>
</tr>
<tr>
<td></td>
<td>144 hrs</td>
</tr>
</tbody>
</table>

(After Powell and Amin, 1969)

II.6 EVAPOTRANSPIRATION AND WATER NEEDS IN COTTON

Water is an important input for crop growth and for maximum production and adequate water supply from the root zone is essential. Water requirements of crops are determined by potential evaporation and crop species. In respect of cotton crop, water is needed for vigorous growth, good budding, fruiting and formation of healthy bolls. Excessive water restricts root growth and crop development. Abrupt changes in water supply may lead to flower and boll shedding. In general, water requirements of cotton crop range between 700 to 1300 mm, distributed as 10% during early vegetative stage and 50-60% during maximum leaf area development and flowering periods and the remaining during the stages after flowering. Two aspects should be considered in this regard, (a) water consumption per unit dry matter production, and (b) variation of water requirements in the different phenophases to meet the evaporative demand determined by prevailing weather conditions.

II.6.1 Water use

Water use at different phenological stages and evapotranspiration rates for cotton crop were reported by Kowal and Faulkner (1975). Peak evapotranspiration rates were observed around the appearance of first flower when ratio of lysimeter evapotranspiration (ET) to open water evaporation (Eo), ranged from 1.06 to 1.07 (Table II.4). These
compared favourably with crop coefficient values, and also ET/Eo values of 1.2 to 1.4 earlier reported by Hutchinson, et al., (1958). Growth phases, corresponding ET/Eo ratios, leaf area index and flower counts are shown in Figure II.15.

Figure II.15. ET/Eo ratio in cotton LAI and flower count (Fc) (Kowal and Faulkner, 1975)
Table II.4

Water use by cotton in the gravimetric lysimeter
(Samaru, North Nigeria, 1971)
All values in mm.

<table>
<thead>
<tr>
<th>10-day periods</th>
<th>Rainfall</th>
<th>Drainage</th>
<th>Soil water storage</th>
<th>Cumulative storage</th>
<th>ET</th>
<th>ET/Eo</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>44</td>
<td>26</td>
<td>26</td>
<td>18</td>
<td>0.35</td>
<td></td>
<td>(sown on 28 June)</td>
</tr>
<tr>
<td>2</td>
<td>31</td>
<td>12</td>
<td>38</td>
<td>19</td>
<td>0.41</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>65</td>
<td>43</td>
<td>81</td>
<td>22</td>
<td>0.51</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>90</td>
<td>51</td>
<td>65</td>
<td>146</td>
<td>25</td>
<td>0.61</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>106</td>
<td>66</td>
<td>6</td>
<td>152</td>
<td>34</td>
<td>0.74</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>72</td>
<td>22</td>
<td>2</td>
<td>154</td>
<td>38</td>
<td>1.06</td>
<td>appearance of 1st flower</td>
</tr>
<tr>
<td>7</td>
<td>119</td>
<td>68</td>
<td>0</td>
<td>154</td>
<td>50</td>
<td>1.04</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>89</td>
<td>40</td>
<td>4</td>
<td>158</td>
<td>47</td>
<td>1.07</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>5</td>
<td>8</td>
<td>10</td>
<td>168</td>
<td>39</td>
<td>0.87</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>0</td>
<td>-54</td>
<td>113</td>
<td>51</td>
<td>0.98</td>
<td>maximum LAI</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>7</td>
<td>-45</td>
<td>69</td>
<td>45</td>
<td>0.90</td>
<td>LAI</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>0</td>
<td>-26</td>
<td>42</td>
<td>34</td>
<td>0.68</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>0</td>
<td>-33</td>
<td>10</td>
<td>33</td>
<td>0.56</td>
<td>half-max LAI</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>0</td>
<td>-16</td>
<td>-7</td>
<td>16</td>
<td>0.33</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>0</td>
<td>-07</td>
<td>-13</td>
<td>7</td>
<td>0.15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>0</td>
<td>-03</td>
<td>-16</td>
<td>3</td>
<td>0.06</td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>0</td>
<td>-02</td>
<td>-18</td>
<td>2</td>
<td>0.05</td>
<td>harvest</td>
<td></td>
</tr>
</tbody>
</table>

(After Kowal and Faulkner, 1975)

At stations with high rainfall variability, average ET/Eo ratios do not represent the pattern of water consumption in the individual years. A typical case in respect of gravimetric lysimeter observation from cotton research station at Coimbatore, in south India (lat. 11°00'; long 76°58') is shown in Figure II.16.

An example of monitoring of water use in relation to different irrigation amounts and soil moisture is provided by Rijks (1976) (Table II.5).
Figure II.16. ET/EP Ratio of Cotton Crop
<table>
<thead>
<tr>
<th>Period</th>
<th>Date</th>
<th>No. of days in period</th>
<th>(E_o) (cm period(^{-1}))</th>
<th>(E_T) (cm period(^{-1}))</th>
<th>Soil moisture (cm)</th>
<th>(L_e) (cm)</th>
<th>(E_o/E_T)</th>
<th>Soil moisture (cm)</th>
<th>(L_e) (cm)</th>
<th>(E_o/E_T)</th>
<th>Soil moisture (cm)</th>
<th>(L_e) (cm)</th>
<th>(E_o/E_T)</th>
<th>Soil moisture (cm)</th>
<th>(L_e) (cm)</th>
<th>(E_o/E_T)</th>
<th>Soil moisture (cm)</th>
<th>(L_e) (cm)</th>
<th>(E_o/E_T)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>17 Sept.</td>
<td>20</td>
<td>13:2</td>
<td>124</td>
<td>41</td>
<td>3</td>
<td>0.16</td>
<td>60</td>
<td>3</td>
<td>0.24</td>
<td>83</td>
<td>7</td>
<td>0.57</td>
<td>99</td>
<td>6</td>
<td>0.49</td>
<td>0.45</td>
<td></td>
<td></td>
</tr>
<tr>
<td>II</td>
<td>7 Oct.</td>
<td>21</td>
<td>13:1</td>
<td>121</td>
<td>39</td>
<td>4</td>
<td>0.33</td>
<td>50</td>
<td>9</td>
<td>0.14</td>
<td>77</td>
<td>5</td>
<td>0.33</td>
<td>89</td>
<td>9</td>
<td>1.14</td>
<td>1.06</td>
<td></td>
<td></td>
</tr>
<tr>
<td>III</td>
<td>28 Oct.</td>
<td>16</td>
<td>8:5</td>
<td>19</td>
<td>35</td>
<td>5</td>
<td>0.14</td>
<td>63</td>
<td>9</td>
<td>1.14</td>
<td>71</td>
<td>8</td>
<td>1.14</td>
<td>89</td>
<td>9</td>
<td>1.06</td>
<td>1.06</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IV</td>
<td>13 Nov.</td>
<td>14</td>
<td>7:6</td>
<td>71</td>
<td>30</td>
<td>2</td>
<td>0.28</td>
<td>63</td>
<td>8</td>
<td>1.12</td>
<td>80</td>
<td>8</td>
<td>1.12</td>
<td>80</td>
<td>8</td>
<td>1.12</td>
<td>1.05</td>
<td></td>
<td></td>
</tr>
<tr>
<td>V</td>
<td>27 Nov.</td>
<td>11</td>
<td>7:4</td>
<td>70</td>
<td>28</td>
<td>1</td>
<td>0.14</td>
<td>77</td>
<td>5</td>
<td>0.12</td>
<td>72</td>
<td>8</td>
<td>1.16</td>
<td>80</td>
<td>8</td>
<td>1.16</td>
<td>1.08</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VI</td>
<td>8 Dec.</td>
<td>14</td>
<td>6:3</td>
<td>59</td>
<td>31</td>
<td>2</td>
<td>0.33</td>
<td>64</td>
<td>5</td>
<td>0.12</td>
<td>59</td>
<td>5</td>
<td>0.12</td>
<td>59</td>
<td>5</td>
<td>0.12</td>
<td>0.79</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VII</td>
<td>22 Dec.</td>
<td>16</td>
<td>7:3</td>
<td>72</td>
<td>31</td>
<td>2</td>
<td>0.28</td>
<td>47</td>
<td>3</td>
<td>0.30</td>
<td>59</td>
<td>7</td>
<td>0.98</td>
<td>59</td>
<td>7</td>
<td>1.04</td>
<td>0.97</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VIII</td>
<td>7 Jan.</td>
<td>14</td>
<td>7:2</td>
<td>67</td>
<td>29</td>
<td>2</td>
<td>0.28</td>
<td>44</td>
<td>2</td>
<td>0.30</td>
<td>52</td>
<td>4</td>
<td>0.98</td>
<td>45</td>
<td>5</td>
<td>1.04</td>
<td>1.04</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>25 March</td>
<td></td>
<td></td>
<td></td>
<td>14</td>
<td>34</td>
<td>45</td>
<td>32</td>
<td>67</td>
<td>32</td>
<td>67</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table II.5. Potential evaporation from an open water surface \((E_o)\), Evapotranspires rates from cotton crop \((E_T)\) and water use \((ES)\) for four rates of irrigation. (After Rijks, 1978)
Monitoring of water balance in rainfed regions is to be carried out to identify water deficiency periods, high evapotranspiration periods to decide supplementary irrigation schedules depending on the growth stage.

Production of fruiting points, flowers mature bolls and yield of cotton was studied by Rijks (1965) in relation to 'available water' in the soil (Fig. II.17). Similar functions if derived for cotton growing regions, can be utilized for predicting yield at different levels of 'available soil water' on operational basis under rainfed conditions.

Figure II.17. Yield, fruiting points, flowers and bolls at four levels of available water (Reproduced from Rijks, 1965)
II.6.2 Water stress

The most easily recognized symptom of water stress is wilting of the leaves. In cotton, discolouring of the stem and appearance of a bluish green colour on the leaves also indicate the symptoms of water stress. Hern (1972) identified relative turgidity of cotton leaves below 83% as a measure of water stress.

II.6.2.1 Effects of water stress

One of the first effects of water stress is, a shortening of the internodes without affecting the timing of node production. Under field conditions one or two of the mainstem internodes may be found to be much shorter than the others indicating that a dry spell had occurred when these nodes were developing. The dry spell can often be dated by reference to the time scale of plant development; only in extreme drought conditions does growth stop completely.

The stage at which moisture stress has the greatest effect on cotton yield is the early flowering period (Marani and Horwity, 1963) when even moderate stress would cause bud and boll shedding (Stockton, et al., 1961). Critical periods for soil water stress in decreasing order of severity respectively are (i) flowering and boll formation, (ii) early growth stages and (iii) after boll formation. During vegetative period, soil water over rooting depth 0-75 cm should not fall below 50% depletion of available water, and during flowering, up to 70% depletion is not considered detrimental to crop growth. Critical plant water potential necessary for unimpeded plant growth (Stem diameter, leaf area and height) to occur lies between -7 and -10 bars of plant-water potential (Jordan, 1970).

A relationship derived between the time of onset of water stress in terms of days/weeks before first boll opening versus yield would enable prediction of yield in relation to water stress duration.

II.6.2.2 Stomatal conductance in sunlit and shaded leaves:

Effect of water stress on leaf conductance in cotton under sunlit and shaded leaves showed that on an average, conductance of daytime shaded leaves to be approximately 41% (under no water stress) and 38% (with severe water stress) of sunlit leaves (Peterson, et al., 1991). Under severe stress, there was no correlation between leaf temperature and leaf conductance. Leaf temperatures were however, 2.5°C higher under stress conditions that those under non-stress conditions (Fig. II.18). PAR was identified as the primary environmental factor affecting sunlit leaf conductance (Fig. II.19).
Figure II.18. Sunlit and shaded leaf conductance for (a) non-stress (b) severe-stress conditions (Reproduced from Petersen, et al., 1991)

Figure II.19. PAR and cotton leaf conductance (Reproduced from Petersen, et al., 1991)
II.6.2.3 Influence of advective conditions

Advective conditions increase ET and water use by both rainfed and irrigated crops due to transfer of energy from the surroundings to the evaporating crop surface. Micrometeorological experiments using vertical profile method for deriving Bowen’s ratio for estimation of evapotranspiration from cotton crop (Rijks, 1971) revealed that the rate of evaporation from an actively growing crop not short of water was often as much as 1.8 times the net radiant energy available at crop surface under influence of both local and general advection. Macro-scale advection due to prevailing weather system itself contributed advected energy at levels of 1.5 times the net radiant energy. The fetch for the cotton plots where local advection became negligible was determined as two hundred meters. Gravimetric determination of soil moisture and lysimetric observations showed that under advective conditions water supply is needed at 1.2 ET near the leading half of the field whereas 1.0 ET was required in the other half (Rijks, 1976).

A simple indicator of presence of advective conditions can be obtained by working out the difference between net radiant energy available and pan evaporation (Sastry, 1969). Whenever pan evaporation rates exceed net radiant energy at the crop surface, presence of advective conditions and energy gain by crop, with a resultant increase in water use, can be suspected. This information estimated on routine basis helps in providing supplemental irrigation if available or in estimating effect of stress on yield reduction.

II.6.3 Canopy-air temperature difference and water stress

Higher canopy temperatures are recorded in crops experiencing water stress. Canopy temperature by itself, and canopy-air temperature difference or derived indices are in use in the past decade for detection of water stress in crops.

Significant correlations between crop water stress index $X$, (CWSI) and normalized lint yields, $Y$, (percentage of yield/maximum yield) in cotton were obtained (Wanjura and Newton, 1981). The regression is as follows:

$$ Y = 93.0 - 23.3X - 30.8X^2 \quad (R^2 = 0.68) $$

Equation suggests a normalized lint yield of 93 and 37% for average CWSI values 0 and 1 respectively. Similar relationships would be of value in estimating water stress and yield on real time basis using canopy temperature data through remote sensing techniques.

II.6.3.1 Thermal stress index

A thermal stress index (TSI) for cotton was proposed by Burke, et al., (1990). This is determined from foliage temperature $T_f$ and the optimum temperature from biochemical point of view $T_b$ ($27.5$ °C for cotton species) and is expressed as

$$ TSI = (T_f - T_b) / T_b $$

This is simpler and of practical value for field operations.
II.6.3.2 Effect of irrigation scheduling on canopy temperature

Wanjura, et al., (1990) in their study with cotton crop used six irrigation treatments which included both soil water deficit and canopy temperature based irrigation schedules listed below.

1 Replacement of soil water in the root zone every week (SWR)
2 Replacement of soil water every 2 weeks after first fruiting stage (AUS)
3 Rainfed conditions after planting (DRY)
4-8 Irrigation when 15 minute average canopy temperature exceeded 28, 30 or 32°C respectively.

Cumulative applied water in the above treatments is shown in Figure II.20.

Rate of boll maturity was higher in DRY treatment followed by 32, 30, 28°C, AUS and SWR treatments. It took 20 days more in SWR treatment compared to all other treatments for attainment of peak number of bolls (Fig. II.21). By the time freezing temperatures set in, SWR treatment had only 45% of mature bolls due to delayed and slower ripening whereas the other treatments recorded 100% mature bolls by this time escaping the hazards of freezing temperatures.

Threshold canopy temperature of 28°C which is close to biochemically optimum temperature for cotton produced higher lint yield comparable to AUS treatment. These results illustrate adaptability of threshold canopy temperature for irrigation scheduling in cotton.

II.6.3.3 Effect of water logging on canopy temperature

It has earlier been mentioned that water logging in cotton crop decreases photosynthetic rates and evapotranspiration. After attaining full canopy level, plants subjected to 8-day water logging (up to 60% of the root zone), showed a slight increase in canopy temperature from the 4th day itself with no visual symptoms on the plant. (Reicosky, et al., 1985). However, by the 8th day, canopy temperatures were observed to be 4 to 6 °C higher than those in non-water logged plants, and also visual symptoms of wilted leaves were noticeable. The ratio Tt and Ta between foliage temperature Tf, and ambient temperature Ta, of water logged and non-water logged plants was derived by Reicosky, et al., (1985) as a crop stress index. Variation of crop stress index with water logging in cotton is given in Figure II.22. A decrease in aerodynamic resistance from 50 to 30 s/m was estimated along with an increase in canopy resistance from the initial value of 20 to 80-100 s/m in the plants subjected to water logging for eight days.

II.6.4 Drought and crop yields

Climatic water balance techniques have often been utilized to characterise drought arising out of absence rainfall over long periods causing both atmospheric and soil drought conditions in cropped regions. Aridity index (Thronthwaite, 1948), Water Requirement Satisfaction Index suggested by Frere and Popov (1979), for monitoring crop drought can gainfully be utilized using real time weather data on a weekly basis. These indices were utilized by Sahu and Sastry (1992b) for estimation of yield thresholds in relation to severity of drought in respect of cotton crop for the Gujarat region in western India (Table II.6).
Figure II.20. Cumulative applied water in six irrigation treatments
(Reproduced from Wanjura, et al., 1990)

Figure II.21. Mature and immature bolls in six irrigation treatments
Figure II.22. Variation in crop stress index with water logging in cotton for different periods
(Reproduced from Reicosky, et al., 1985)
Table II.6. Seasonal rainfall, aridity index, WRSI and estimated average yields for rainfed cotton (Gujarat state, India)

<table>
<thead>
<tr>
<th>Seasonal rainfall (mm)</th>
<th>Drought class</th>
<th>Aridity index</th>
<th>WRSI</th>
<th>Yield (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1486</td>
<td>no drought</td>
<td>17</td>
<td>80</td>
<td>&gt;200</td>
</tr>
<tr>
<td></td>
<td>moderate</td>
<td>17-25</td>
<td>80-60</td>
<td>200-140</td>
</tr>
<tr>
<td></td>
<td>severe</td>
<td>&gt;25</td>
<td>&lt;60</td>
<td>&lt;140</td>
</tr>
<tr>
<td>910</td>
<td>no drought</td>
<td>33</td>
<td>75</td>
<td>200</td>
</tr>
<tr>
<td></td>
<td>moderate</td>
<td>33-53</td>
<td>75-60</td>
<td>140</td>
</tr>
<tr>
<td></td>
<td>severe</td>
<td>&gt;53</td>
<td>&lt;60</td>
<td>&lt;140</td>
</tr>
<tr>
<td>592</td>
<td>no drought</td>
<td>48</td>
<td>65</td>
<td>&gt;190</td>
</tr>
<tr>
<td></td>
<td>moderate</td>
<td>48-70</td>
<td>65-40</td>
<td>190-130</td>
</tr>
<tr>
<td></td>
<td>severe</td>
<td>&gt;70</td>
<td>&lt;40</td>
<td>&lt;130</td>
</tr>
<tr>
<td>553</td>
<td>no drought</td>
<td>63</td>
<td>50</td>
<td>&gt;190</td>
</tr>
<tr>
<td></td>
<td>moderate</td>
<td>63-84</td>
<td>50-35</td>
<td>190-120</td>
</tr>
<tr>
<td></td>
<td>severe</td>
<td>84</td>
<td>&lt;35</td>
<td>&lt;120</td>
</tr>
</tbody>
</table>

(Sahu and Sastry, 1992b)

Results show that different threshold values exist for both Aridity index and WRSI for the same crop species at each location depending on the local soil and climatic conditions.

II.7 SUNSHINE, LIGHT INTENSITY AND GROWTH

Physiologists have recognised the high ability of cotton crop to utilize solar energy. Light rarely limits growth of cotton plant under field conditions. In the temperate zone itself, the intensity of sunlight at midday is estimated to be four to five times more than that needed for optimum growth of the cotton plant.

II.7.1 Cloudiness

Shedding percentage of young bolls increases due to cloudy days, the result often appearing about a week later (Dunlap, 1945). Four hours of sunshine per day seems to be essential for boll retention (Goodman, 1955), but however, no direct influence between cloudiness and boll shedding had been established with certainty as several factors interact in the process.

II.7.2 Critical light intensity

A light intensity of 2 Klx reaching subtending leaves, especially the 5th leaf, was arrived at as the critical intensity at which there could be as much as 87% of boll shedding by Jiang, et al., (1984). At higher light intensities, lower shedding rates were observed.
For mainstem leaves, 2.5 Klx was stated as the critical limit.

In general, 2.5 Klx can be defined as the critical limit for light intensity in respect of cotton crop.

II.7.3 Light transmission

Jones, et al., (1980) observed that light transmission through a cotton canopy was a linear function of leaf area index. Light transmission coefficients among three cultivars studied by Rosenthal and Gerik (1991) did not show significant differences. While radiation use (RUE) efficiencies in the three cultivars were not significantly different during the vegetative stage, they ranged from 1.3 to 1.5 g/MJ during the reproductive period. These are lower than RUE of 2.5 g/MJ observed by Howell and Meek (1983) for irrigated cotton grown in California. Dry matter accumulation pattern in relation to PAR among different varieties is shown in Figure II.23.

II.7.4 Phosynthetically active radiation and lint yield

Comparison of light interception by cotton canopy (Heitholt, et al., 1992) with normal leaf pattern and in the narrow row cotton with cv. Okra, which has small leaf with moderately cleft pattern showed that seasonal insolation interception was highly correlated with lint yield for late plantings (Fig. II.24). They had also derived PAR as a function of cumulative heat units (Fig. II.25) which have practical application in crop growth modelling.

II.7.5 Albedo and microclimate

For cotton, after onset of flowering, an albedo value of 0.17 was derived by Stanhill and Fuchs (1968) while Budyko (1958) put it in the range 0.20-0.25. Velinskii (1960) quoted albedo of 0.20, 0.21 and 0.18 for clear, partly cloudy and cloudy weather respectively. In the early growth stages, with low crop cover, it could be as high as 0.44. Being subject to high variability due to plant to plant distance and row spacing, irrigation treatment, latitude and crop colour, leaf area, etc., it is useful to define these values through field experiments locally for specific conditions.

Stanhill and Fuchs (1968) observed that after crop height had reached 33 cm, the relationship between wind speed over crop and wind speed over bare field remained approximately the same for the remainder of the season and no further influence of crop height or structure could be distinguished. Moreover, at high wind speeds, the velocity measured one meter over the mature crop was approximately 2/3 of the value measured at a similar height above bare soil.

Wind profile measurements over irrigated cotton crop in Sudan by Jarman (1959) showed a roughness length of 14 cm with a zero plane displacement of 45 cm. Influence of crop height or structure is not distinguishable after the crop attains a height of about 35 cm (Stanhill and Fuchs, 1968). These are representative values and need to be determined for local conditions.
Figure II.23. Dry matter accumulation in cotton in relation to PAR
(After Rosenthal and Gerik, 1991)
Figure II.24. Insolation interception and lint yield in cotton (Heitholt, et al., 1992)

Figure II.25. PAR interception and heat units (Heitholt, et al., 1992)
II.8 INSECT PESTS AND DISEASES IN COTTON AND WEATHER FACTORS

Cotton plant is attacked by several diseases and pests. The green succulent leaves, open flowers, nectaries on every leaf and flower and a vast amount of fruits of the cotton plant attract insects, aphids, and jassids. Fungal, wilt and blight diseases are some of the most important ones affecting the plants growth and yield.

II.8.1 Pests in cotton

II.8.1.1 Boll weevil (*Anthonomus grandis*)

The damage caused by the boll weevil varies greatly from year to year. The supply of feeding and breeding material which is affected by weather conditions during the late summer and early fall, determines the number and condition of boll weevils for hibernation.

Studies under both constant and fluctuating temperatures under controlled conditions (Watson, et al., 1986) showed that development from egg to adult at constant temperatures of 25, 30 and 35°C occurred in 38, 24 and 16 days respectively. Under lower fluctuating temperatures between 21-34°C, the development time was 21 days, and mortality was generally higher. A temperature of 39°C is considered as the upper lethal threshold for boll weevil.

The temperature range between 25 to 35°C may be defined as optimum, with lower and upper thresholds at 21 and 39°C respectively for development of boll weevil in cotton.

II.8.1.2 Pink Boll Worm (*Pectinophora gossypiella*)

The adult of a pink boll worm is a small brown moth. During the daytime the adult moths are inactive and are seldom seen even in a heavily infested field. The eggs are small, white and oval shaped and have a finely wrinkled surface. The eggs hatch within 4 to 5 days in summer and the tiny larvae bore into the boll or square. During summer most of the larvae cut holes through which they leave the boll, dropping to the ground to pupate in the surface trash or cracks in the soil.

The worms thrive in warm but not excessively hot weather. Cloudiness and frequent but not excessive rains are good for its development. Long spells of dry hot weather are associated with the lowest pink boll worm incidence. Larval incidence is known to increase with the development of the boll up to 3 weeks and decline thereafter (Rao, et al., 1983). Plant protection measures at this time are considered useful, and observation of phenology is important. Larvae can survive within the green bolls at temperatures exceeding 44°C for 5 hours but are not known to multiply (Chu, 1987). Laboratory investigations at 30, 40°C for 8 hours also gave similar results. However, at 50°C the mortality of larvae inside the bolls was estimated to be about 67 per cent but for those larvae exposed outside it was 94 per cent.

Temperature and diet were shown to be closely related to oviposition of the pink bollworm (Shu, 1986). The adults oviposit in the temperature range 18 to 37°C beyond which longevity decreases with increasing temperature.

For all bollworms: An average temperature of 28°C was found to be most favourable for population build-up with optimum R.H. of 65-85 per cent. (Katyar, 1982)
II.8.1.3 Spotted Boll Worm (*Earts spp.*)

Two species are common where climate is moderate. In India, *E. fabia* was observed in areas with highest rainfall (more moist regions) in southern parts of India, whereas *E. insulana* was observed in drier regions of northwest India. They appear soon after withdrawal of monsoon rains and declines by December in the cold winter period.

II.8.1.4 Boll Worm (*Heliothis armigera*):

The bollworm destroys the squares and bolls by eating them. The eggs of the bollworm are laid on the leaves and outsides of the squares, and the caterpillars do not remain in a single boll, but bore out again and crawl from square to square, a single boll worm often destroys all the furits on a branch of the plant.

As could be expected, temperature and period of development show an inverse relationship within the temperature limits. The temperature limits for the development of eggs range from 14 to 38°C. Eggs hatch in about 3 days in hot weather but at a mean temperature of 17°C it may take 9 days.

It takes 35 days at 20°C for larvae development, and as temperature is increased, the duration decreases to 17 days. (Butler, 1976). Optimum temperatures reported by him are as follows:

<table>
<thead>
<tr>
<th>Stage</th>
<th>Optimum °C</th>
<th>Stage</th>
<th>Optimum °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Egg</td>
<td>34</td>
<td>Pupa</td>
<td>35</td>
</tr>
<tr>
<td>Larvae</td>
<td>36</td>
<td>Adult</td>
<td>42</td>
</tr>
</tbody>
</table>

Haggis (1983) reported that laying of *H. armigera* eggs reaching endemic proportions was noted in North Sudan three days immediately following rainfall but interestingly over the areas outside, adjoining the rainbelt and not within the rain area itself (Fig. II.26). It is surmised that this event is associated with the southward movement of Inter-tropical Discontinuity (ITD) rather than with rainfall.

II.8.2 Cotton Jassids (*Empoasca devastans*)

These are observed to increase with increased irrigation and may occur with high rainfall. The life cycle is not more than 3 weeks, and multiplication under favourable weather conditions is very fast. Heavy attacks were observed both in seasons of light and heavy rain and sometimes drought conditions.

II.8.3 Cotton Aphids (*Aphis gossypii*)

These are small, ovate gregarious insects with an average life of about 4 weeks for an individual aphid. Rate of development increases between 17 and 28°C with an optimum for reproduction at 19-20°C (Munro, 1987). At a 5-day period average temperature (AFTD) ranging from 17.6 to 24°C, a 20 to 30-fold multiplication was
recorded (Pan, et al., 1986). At AFTD below and above this temperature range, reproduction was 4 and 20 times respectively, indicating that higher temperatures are more favourable for multiplication.

The temperature range of 18 to 24°C can be defined as optimum for development of the cotton aphid.

![Graph showing the relationship between temperature and cotton aphid egg counts.](image)

**Figure II.26.** Rainfall areas and population of *H. armigera* eggs in the Gezira, Sudan.

(Reproduced from Higgs, 1981, no reference)
II.8.4 Cotton diseases

Several important cotton diseases such as the bacterial blight and fusarium wilt occur in all the main cotton growing regions of the world. Changes in agronomic practices, and introduction of disease resistance in the newly developed varieties from time to time have over the years, altered the relative importance of some of the pathogens. The cotton diseases have been described by Hillocks (1992) which is a source book for the material described below.

II.8.4.1 Seedling diseases

Seedling diseases in cotton are a worldwide problem often causing serious stand loss where it is not controlled. A number of soil and seed borne micro-organisms can infect cotton seedlings individually or in association as a disease complex.

Table II.7 Micro-organisms identified a primary seedling pathogens
(After Hillocks, 1992)

<table>
<thead>
<tr>
<th>Organism</th>
<th>Optimal temperature for disease °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fungi</td>
<td></td>
</tr>
<tr>
<td>Alternaria alternata</td>
<td>25-30</td>
</tr>
<tr>
<td>Alternaria macrospora</td>
<td>25-30</td>
</tr>
<tr>
<td>Alternaria solani</td>
<td>25-30</td>
</tr>
<tr>
<td>Ascichyta gossypii</td>
<td>25-30</td>
</tr>
<tr>
<td>Colletotrichum gossypii</td>
<td>22-25</td>
</tr>
<tr>
<td>Fusarium moniliforme</td>
<td>20-25</td>
</tr>
<tr>
<td>Fusarium oxysporum</td>
<td>20-25</td>
</tr>
<tr>
<td>Fusarium solani</td>
<td>21</td>
</tr>
<tr>
<td>Macrophomina phaseolina</td>
<td>30-35</td>
</tr>
<tr>
<td>Pythium aphanidermatum</td>
<td>20-25</td>
</tr>
<tr>
<td>Pythium ultimum</td>
<td>18-20</td>
</tr>
<tr>
<td>Rhizoctonia solani</td>
<td>24-32</td>
</tr>
<tr>
<td>Sclerotium rolfsii</td>
<td>25-30</td>
</tr>
<tr>
<td>Thielaviopsis basicola</td>
<td>16-20</td>
</tr>
<tr>
<td>Bacteria</td>
<td></td>
</tr>
<tr>
<td>Xantahomonas casestris</td>
<td>26-28</td>
</tr>
<tr>
<td>Virus</td>
<td></td>
</tr>
<tr>
<td>Leaf crumple virus</td>
<td>-- -- --</td>
</tr>
<tr>
<td>Nematodes</td>
<td>-- -- --</td>
</tr>
<tr>
<td>Meloidogyne incognita</td>
<td>30</td>
</tr>
<tr>
<td>Rotylenchulus reniformis</td>
<td>30</td>
</tr>
</tbody>
</table>

The term seedling disease describes any host-pathogen interaction which debilitates or kills the plant between planting and about four weeks after emergence. The plant part that is affected and the growth stage at which it occurs had been used by Hillocks (1992) to divide disease symptoms into four groups.
1. Damage occurs immediately after planting resulting in seed decay.

2. The newly emerging roots and shoot may be vulnerable to attack under conditions unfavourable to plant growth resulting in pre-emergence damping off.

3. Attack of the seedlings by soil borne fungi after emergence and infection of the hypocotyl.

4. A distinct spotting or a generalized blight on the cotyledons and first leaves.

II.8.4.2 Seed decay

Conditions favouring infection:

Contamination of the seed by micro-organisms may occur due to exposure to adverse weather conditions at the pre- and post-harvest (storage and transport) stages. Under well-aerated, dry atmosphere at 20-25°C cotton seed can be stored for a number of years without loss of viability (Hallow and Bourland, 1981). In the pre-emergence period, *Pythium* spp assumes importance while in the post emergence period, *Rhizoctonia solani* seems to be the most significant cause of damping-off throughout the world.

II.8.4.3 *Rhizoctonia solani*

The optimum temperature for infection of cotton seedlings depends on other environmental factors, inoculum count and variation between isolates. Hunter and Staffeldt (1960) demonstrated that a mildly virulent strain could cause maximum damage at 24°C a moderately virulent strain at 32°C, while a virulent strain count be highly pathogenic over a wide temperature range from 24 to 32°C. Optimum relative humidity has been stated to be 100% for infection in case of *R. solani*. Baker and Martinson (1970) reported 20-80% of field capacity of soil as optimum soil moisture content, showing that infection can take place over a wide range of soil moisture levels.

A temperature range of 24-32°C and 100% relative humidity in the ‘available water’ range in the soil can be defined as the optimum criteria for infection of *R. solani*.

II.8.4.4 *Pythium* spp.

Seed rot and pre-emergence damping off in cotton seedlings are the symptoms of the occurrence of *Pythium* spp. while at later growth stages of the plant, this may cause stunting or chlorosis.

Low temperatures and high soil moisture content are the most damaging conditions for cotton. Arndt (1943) suggested a temperature range of 18 to 20°C and 60 per cent soil moisture content as the most optimum for the disease development in to epidemic proportions. The population was found to increase slowly at 9-11°C and most rapidly on the range 15-20°C (Hancock, 1981).
II.8.4.5 *Colletotrichum* spp.

This fungus causes cortical rot at the base of the hypocotyl in the seedlings but is also most damaging to the bolls at the later growth stages of the cotton plant. Infection is low below 20°C and more pronounced between 20-26°C with an optimum at 25°C and >90 per cent relative humidity. Upper threshold is at 36°C (Davis, et al., 1981, Arndt, 1944, 1953).

II.8.4.6 *Theilaviopsis basicola*

The infection normally occurs at the seedling stage, causing a root rot, with a sudden collapse of leaves. Soil temperatures in the range 16-20°C and with high soil moisture content had been reported to affect the seedlings (Mauk and Hine, 1988). Disease symptoms are most severe under cool wet conditions and appear after irrigation in soils with slow drainage characteristics. It has a lower threshold of 3°C for germination, with a rapid increase at 10°C and with an optimum temperature between 20-33°C germ tube growth is restricted at temperatures above 30°C (Mathre and Ravenscroft, 1966).

II.8.5 Bacterial Blight

Bacterial blight affects the cotton plant at all stages of its development. Beginning with the seedling, it affects leaves, followed by the main stem and the bolls. The disease is known by different names at different growth stages.

- **Seedling blight** -- in young seedlings
- **Angular leaf spot** -- on the leaves
- **Black arm disease** -- on the stem and bolls

The lower and upper thresholds for disease development are 10°C and 38°C respectively with an optimum between 25-30°C. Massey (1929, 1934) brought out the importance of soil temperatures for the primary infection of the seedling. Infection was not observed in the germinating seeds at temperatures of >30°C and very little infection at 28°C. Disease development was slow below 15°C and only mild infection occurred between 16-20°C. Severe infection was limited to soil temperatures in the range 26-28°C. Free water was regarded as essential for infection and seedlings in poorly drained soils are heavily infected.

At high relative humidity (>90 per cent) with high daytime temperatures of 36°C and with moderately low night temperatures of 19°C the disease development had been found to be most severe. This would define optimum conditions for disease multiplication. However, at 25°C infection was greatest at 85 per cent RH, and only slight at 70 per cent RH. In northern India, severe blight incidence was recorded at locations where RH was 75 per cent or more for at least ten weeks of the growing season. Rain at four to six weeks after planting was regarded as a warning of possible epidemic conditions (Verma and Singh 1971).

Optimal conditions for the development of bacterial blight epidemic summarised by Hillocks (1992) are as follows:
1. The establishment of primary infection at the seedling stage

2. Early rainfall to distribute the disease through the crop within six weeks after planting.

3. Periods of heavy wind-driven rain after canopy has formed together with interspersed periods of sunshine and with an RH of over 85 per cent within the crop.

4. High temperature during the secondary phase of the disease with temperatures in the range 32-38°C during the day and 17-20°C, at night.

II.8.5.1 Verticillium wilt

Verticillium and Fusarium wilt are the two vascular wilt diseases affecting cotton plants. Plants infected at the fruiting stage develop characteristic mosaic pattern on infected leaves and with the progress of the disease development, many of the leaves and young bolls get defoliated. Infection generally occurs during the period when mean temperatures are below 30°C when the symptoms also appear.

The optimal temperature for fungal growth is 22-27°C with some isolates growing slowly at 32°C. Temperature is usually the greatest limiting factor to the growth of the fungus in the cotton plant during most of the growing season. Temperature optima are known to change in relation to water supply (Bell and Presley, 1969., De Vay and Pullman, 1984). At water potentials of -30 to -40 bars, the fungus grows at 35°C but when water potentials are higher, growth is limited to below 30°C.

With decrease in temperature, the severity of the disease decreases progressively down to 22°C. With adequate water supply in the root zone, 22-27°C can be defined as the optimum temperature range for the disease.

II.8.5.2 Fusarium wilt

Fusarium wilt is a problem in areas with mean daily temperatures above 23°C. The plants are more susceptible at flowering stage. Chlorosis in patches and extensive defoliation are the symptoms observed in the advanced stages of the disease.

Spores germinate at an optimum temperature of 25°C with a maximum at 30°C with 100 per cent relative humidity. At temperatures below 23°C and at relative humidity less than 80 per cent, germination fails to occur (El Abyad and Saleh, 1971).

By the time a well grown cotton crop reaches the stage of boll production, the crop canopy is dense with large leaf surface. This provides a humid microclimate within the crop creating an environment where phylloplane micro-organisms can flourish.

II.8.6 Alternaria leaf spot

The earliest symptom of this disease is the appearance of spots on the cotyledons and with further plant growth, on the lower leaves. Bashi, et al., (1983) found that the
minimum temperature for the disease to occur was 10°C with a four hour duration of leaf wetness. It has an upper threshold of 35°C with an optimum in the temperature range 20-25°C. A twenty hour leaf wetness is the optimum for leaf infection.

Peak sporulation was observed at 30°C on green leaves, at 25-30°C on chlorotic leaves and at 20-30°C on necrotic leaves. Sporulation was found to be five times more prolific on five week old leaves than on seven week old leaves. (Rotem, et al., 1989). The upper threshold for lesion formation is 39°C. A temperature range of 20 to 30°C can be identified as optimum for disease multiplication.

II.8.7 Cercospora leaf spot:

Symptoms are irregular brown lesions usually surrounded by a considerable area of chlorotic tissue. Conditions of infection had been reported to be similar to alternaria leaf spot mentioned above.

II.8.8 Grey or False Mildew

This appears first on the lower canopy leaves after setting up of first boll. Mycelial growth is most rapid at temperatures between 20 and 28°C. Conidia and ascospores germinate in free water at temperatures of 16-34°C with optimum between 25 and 30°C. Stomatal penetration by conidia is greater under alternating cycles of night leaf wetness and daytime dry situations than under continuous wetting. Initial infection was observed after two such cycles with maximum infection after four cycles. Germ tubes can survive several 16 hour cycles at 20-60 per cent RH (Rathaiah 1973, 1977).

Other diseases that can be mentioned are the Ascochyta Blight (USA and Africa), the Southwestern cotton rust (Southwest USA, Mexico) and the myrothecium leaf spot (India) for which quantitative weather factors promoting the disease are yet to be worked out.

II.9 RECOMMENDATIONS AND CONTRIBUTION TO CARS

The present report has been compiled from the materials collected from the replies to the questionnaire received from various countries and the survey of literature. The following recommendations are made considering knowledge that is required for improved management of growth, development and final yield of the cotton crop.

RECOMMENDATIONS

1. Agroclimatic classification for cotton crop based on climatic and soil data and using risk factors should be encouraged.

2. Studies should be carried out to identify the specific meteorological thresholds for the incidence and development of pests in cotton crop in order to prepare forecasts and take remedial measures.

3. Remote sensing techniques should be increasingly used for assessment of crop
acreage, water, nutrient and disease stress and the required spectral signatures and ground data should be generated through future experiments.

4. Phenology information for cotton crop for major varieties grown within a country should be developed.

5. Studies on micrometeorology of the cotton crop should be undertaken as these are very much lacking.

6. Steps should be taken to integrate results from laboratory and field experiments for evolving comprehensive prediction models for the different agrometeorological operations using routine weather data. Development of Expert system for specific problems should receive priority.

Contribution to Climate Application Referral System (CARS)

Several threshold values have been identified for different events in the report. These thresholds could be included in CARS. This would enable reanalysis of vast climatological data series with specific reference to the threshold values for the cotton crop.
II.10 BIBLIOGRAPHY


Smith, C.E., Jr (1968) (quoted by Munro, 1987).


ACKNOWLEDGEMENTS

The author wishes to place on record his thanks to Dr. N. Chattopadhyaya and Mr. Jayanta Sarkar for their assistance. Sincere thanks are also due to the 18 Member-countries whose replies to the WMO questionnaire on the subject eased the work which otherwise would have taken considerable time. Finally, the author thanks Mr. V.N. Jadhav, Mr. K.H. Kumbhar, Mr. P.K. Sharma, and Mr. Y.G.H. Khan for the assistance received from them in preparation of this report.
III. REPORT ON SOYA BEAN CROP

Agrometeorological information on Soya-bean Crop

by

Dr Kenneth G. Hubbard*

(Rapporteur on Definition of Agrometeorological Information Required for Soya-Bean Crop)

* Department of Agricultural Meteorology
University of Nebraska, Lincoln, Nebraska, USA
AGROMETEOROLOGICAL INFORMATION ON SOYA BEAN

III.1 INTRODUCTION

The earliest known mention of soya bean (Glycine max (L.) Merr.) is in historical references from China (1). Soya bean may have originated in east Asia (1,2) although the origin is clouded somewhat by the fact that cultivated soya bean has never been found in the wild (2). Argentina, Brazil, China, and The United States of America account for 90 to 95 per cent of the soya bean production in the world (3). Although geographical extent of soya bean is not as wide as crops such as wheat, the local land use in some regions, such as portions of the Mississippi River valley in the U.S., reaches 25 per cent of all surface area.

Soya bean is a C₃ plant. Morphologically the soya bean is an annual woody plant attaining a maximum height of 75-125 cm. It may be sparsely or densely branched, depending on variety and growing conditions (4). Leaves and pods may be smooth or pubescent (hair-like). Phasic development in some soya bean varieties is sensitive to day length but, both determinate (floral initiation limited to a fixed period) and indeterminate (floral initiation extending to time of maturity) varieties exist.

In general, non-stressed soya bean will use 500 mm or more of water and require from 65 to 90 days to reach maturity in optimal temperature environments. Some varieties may require as little as 300 mm of water and some nearly 800 mm depending on the inherited characteristics and the evaporation environment. Most varieties thrive on warm day and night temperatures; and while optimum temperature environment is 22 to 30°C, temperatures less than 13°C significantly retard growth. The short day varieties remain in vegetative growth during long days and begin to produce flowers and set fruit when the days are relatively short. Day-neutral or indeterminate varieties of soya bean exhibit little if any response to daylength (5).

III.2 AGROMETEOROLOGICAL INFORMATION IN FARMING

Certain climate features are considered hazardous to the production of soya bean while others are more properly considered a resource. Frost or hail are examples of the former while dependable precipitation is an example of the latter. Examples of these agrometeorological hazards and resources are given below to allow the reader to compare the conditions for soya bean development in two locations. Urbana, Illinois, USA (40° 36’N, 88° 14’W, elevation 226 m) is situated in the middle of a concentrated soya bean production area where over 20 per cent of the land use is for soya bean production. Grand Island, Nebraska, USA (40° 58’N, 98° 19’W, elevation 56 m) is located on the western edge of the main soya bean production area in the U.S. where about 3 per cent of the land use is for soya bean production. These two locations will be referred to below by name or as areas suitable for high soya bean land use (high SLU) and low soya bean land use (low SLU), respectively.

III.2.1 Choice of cropping system

The agrometeorological conditions must be examined to ensure that sufficient moisture is available to the crop to ensure reasonable growth and development. The annual precipitation alone can be somewhat misleading in this regard because of run-off,
evaporation, and other non-transpirational dispositions of rainfall. In a high SLU location such as Urbane the average annual rainfall is 941 mm while in Grand Island the mean annual rainfall is 610 mm. For a high yielding soya bean crop to reach its potential field, it will require about 500 mm of annual rainfall. Although Grand Island's annual rainfall exceeds this amount, the amount lost to evaporation, run-off, and deep percolation make the area marginal for soya bean and therefore low SLU. Crop models that account for the water balance terms can be used to estimate yield potential for an area if sufficient weather data is available. For the high SLU location, the mean annual rainfall exceeds crop water requirements by over 400 mm.

At higher latitudes one must also determine whether the probability of late-spring or early-fall hard-freeze is acceptable low. Continuing our illustrative comparison, the high SLU location has an average growing season length (between 0°C freezes) of 184 days, whereas the low SLU location the mean length of the growing season is 161 days.

Choices of cropping system includes double cropping rotation, strip intercropping, and relay intercropping (6,7,8). To promote sustainable aspects of row-crop systems, continuous cropping patterns generally would be replaced by multi-year rotations, including field crops, legumes, and forage crops. Soya bean would play a key role in common rotations (9).

Choice of crop is not as simple as choosing the crop whose requirements best matches the existing agrometeorological conditions. A recent comparison of 13 cropping systems, including an "organic" rotation that used a non-synthetic chemical, indicate that rotations have higher yields and higher net returns that continuous mono-cropping systems (10). Continuous cropping systems such as corn, soya bean, or sorghum require higher expenditure for pesticides and exhibit greater year-to-year variation in yields and profits.

### III.2.2 Sowing Decisions

Planting date and maturity range are important considerations related to sowing (7). The response of soya bean to planting date depends mainly upon the environmental conditions of temperature, daylength (photoperiod), and moisture distribution subsequent to planting (6,7). At higher latitudes, sowing can proceed when the ground has warmed sufficiently (effective germination occurs above 6-7°C) provided the risk of freeze to above ground plant tissue is acceptably low. Agrometeorological information is critical to the decision because the air will often be warm enough to support soya bean development well before the risk of freeze has past. Using the high SLU location as an example the mean day of the year (DOY) when the minimum temperature first rises above 10°C is DOY 88 however, the last occurrence of a minimum temperature less than 0°C is DOY 110. For the low SLU location the mean first occurrence of minimum temperature in excess of 10°C is on DOY 105 and the mean last occurrence of minimum temperature less than 0°C is on DOY 119. Thus, at these latitudes, the recommendation based on agrometeorological information is to resist the urge to plant during the first occurrence of apparently suitable temperatures. The extra development potential is low due to the cool nights and the risk of frost damage is high enough to offset any gains in crop yield potential.

At lower latitudes the concern is whether sufficient moisture is present or will occur soon after sowing for effective emergence and early development. Occurrence of precipitation prior to emergence increases the likelihood of soil crusting, so shallower planting depths (3 to 4 cm) should be used where a potential problem exists.
Choice of variety will affect yield potential with the longer season varieties having greater yield potential. Seeds produced commercially are rated by time to maturity expressed in calendar days or growing degree days. In the mid-latitudes, a variety should be selected based on the probability of accumulating adequate heat or growing degree day (GDD) units during the growing season. For the high SLU location, the average accumulation of growing degree day units (base 10°C and upper limit 30°C) is 1840 and in only 25 per cent of the years are GDD accumulations less than 1710. For the low SLU location, the average accumulation of GDD is 1671 and in only 25 per cent of the years are GDD accumulations more than 1797.

III.2.3 Timing and nature of cultivations, including field preparation

Land is prepared for planting soya bean by creating a level seedbed. The amount of field work required prior to planting depends upon the residue present from the previous crop and the planting method. Minimum tillage is gaining in popularity and is effective when weeds are properly controlled. In fact, shallow and minimum tillage favour reduction of annual weeds because with this management most of the seed bank for these plants is below the depth where germination will occur and there is no disturbance to bring these idle seeds to the surface. Commercial planting can follow a narrow (15 to 20 cm) row spacing or a wide (75 cm) row spacing. Wider row spacing is practiced where cultivation will be used to control weeds. These systems produce comparable yields provided the weeds are controlled. Use of deep tillage will not ensure amelioration of drought stress even though rooting depth may be enhanced (16).

III.2.4 Timing and nature of sprays and fertilizer

The soil can be tested to determine whether it is sufficiently fertile to ensure satisfactory production (7). Soya bean does not need nitrogen (N) fertilizer provided the seeds have been properly inoculated with a nodule-forming bacteria just before planting (23). Phosphorus (P) and potassium (K) levels are important while calcium, magnesium, and sulfur can also play a role. Micronutrients include boron, copper, iron, manganese, molybdenum, and zinc (7). Soil testing should be conducted sufficiently far in advance of sowing time so that results of testing are available for any fertilizer decisions involving incorporation prior to or during sowing. With modern equipment fertilizers can be placed in the row or in bands adjacent to the row at the time of sowing.

Soya bean ranked fourth out of 25 crops when rated for competitiveness with weeds based on the mean percentage of yield reduction caused by weeds (11). Spraying herbicides for the control of plant pests is usually of optimum benefit when the undesirable plants are treated early in their life cycle. Selective herbicides can be used to control grasses while contact herbicides can be applied directly to weeds. In the case of contact herbicides treatment is usually easiest to accomplish when weeds are slightly taller than soya bean plants and thus easily marked by the applicator. Agrometeorological information can be used to predict weed and soya bean development and height.

Timing of chemical application to control insects and diseases requires a knowledge of what pests and diseases to look for and physically scouting fields. Alternatively, degree day accumulations can be used to predict the emergence and life stage of insects thus reducing scouting time.
The application of chemicals by releasing aerosols from an elevated source as in crop spraying from airplane (crop dusting) or irrigation system (chemigation) is common. The distance moved by the aerosols after release, relative to the release point is known as drift. Meteorological conditions affect the amount of the chemical reaching the target or likewise, the chemical reaching non-targeted areas. Some of the factors involved are particle size, spray system aerodynamics, release height, wind speed, wind direction, turbulence, thermal currents, evaporation, and atmospheric stability. For droplets the sedimentation or settling velocity ranges from 0.01 m s\(^{-1}\) for a 20 μm droplet to 2 m s\(^{-1}\) for a 500 μm droplet. The upper limit on spray drift (x_{max}) has been derived (12) from diffusion theory, x_{max} = \frac{h \left(\ln(h/e^{2})\right)\left(k(v_s/u_f)\right)-b}{k}, where h is the release height, \(z_e\) is the roughness length, \(k\) is von Karman's constant, \(v_s\) is the sedimentation velocity, \(u_f\) is the friction velocity, \(e\) is 2.718, and \(b\) is 1.3.

III.2.5 Irrigation amount and frequency

Water requirements of soya beans are usually as much or more than other summer crops. Studies indicate that 500 to 800 grams of water are needed for each gram of dry matter produced (13,14,15). The ratio of the amount of water used by a crop to the reference evapotranspiration on a daily basis is known as the crop coefficient. Soya bean at full canopy typically uses 8 mm of water per day (25) and crop coefficients may reach 1.2. Most soya bean production takes place under natural rainfed conditions. However, as natural rainfall and soil properties interact to make less stored water available to plants, the importance of irrigation to maintain stable production of soya beans increases (16). Indeterminate soya bean crops have a drought avoidance mechanism whereby a late season rainfall can still produce favourable yields. This is an advantage over determinate type soya bean or maize when rainfall is erratic and/or when there is a high probability that irrigation water will be less than desired.

Comprehensive agrometeorological measurements can be used to estimate the water use of soya bean and soil water deficits (14). Irrigation can then be scheduled to replenish soil water in a timely manner, thus avoiding deficits that produce negative effects on yield.

III.2.6 Harvest decisions

Soya bean seeds may be harvested for oil, meal, or other food products. Alternatively, plants may be grazed for forage or harvested for hay. Harvesting the plants for forage or hay may be the best alternative when it is obvious that seed production will be very low. Timing of harvest can be predicted in advance by utilizing the climatological history of a nearby weather station and the maturity information specific to the selected soya bean variety. The degree day accumulation associated with maturity of soya bean is used as a target and the date on which this GDD total is reached is used as an estimate of maturity dates for soya bean for all years in the historical record. The results from all years are averaged to give a predicted maturity date. Probability levels can be associated with other dates.

III.2.7 Post harvest operations

Generally, soya bean should be stored at low (14%) moisture content. A temperature of 5°C with good aeration is recommended (7). Using outside air and forced
ventilation to dry stored soya bean requires a knowledge of the atmospheric temperature and humidity so that drying times can be calculated.

III.2.8 Duration of growth

A general schedule of phenological events is as follows (4,17,18). Radicle emergence occurs 1 to 2 days after planting. Floral initiation occurs within three weeks after plant emergence. For indeterminate varieties the beginning of flowering is usually observed within 6 to 8 weeks after plant emergence and has a 3 to 4 week duration. Duration of seed development to physiological maturity is from 65 to 75 days after floral initiation. Agrometeorological information can form a more precise estimate of the duration of each phenological stage by associating degree day accumulations with each growth stage. There are approximately 56 degree-days (base 10°C) associated with the appearance of each leaf but, some evidence indicates changing thresholds (19). Germination thresholds are 6 to 7°C. Seedling emergence thresholds are 8 to 10°C. Pod setting thresholds are 18°C.

Phasic development responds to daylength and water availability in addition to temperature (20). The SOYPHEN model predicts developmental phenological stages for varieties in various maturity groups based on environmental inputs.

III.2.9 Rage of growth

The increase in area of individual leaves depends on the temperature but, the appearance of successive leaves or nodes on a mainstem has a more telling effect on the increase in plant area (22). Rate of photosynthesis depends on amount of light and increases with increasing light intensities until the light saturation point is reached. Plants grown in green houses show light saturation at 20 Klux while field-grown soya bean are not saturated at 150 Klux (19).

III.2.10 Yield and stress

Soya bean yields are a complex integration of environmental factors during the growth and development of the plants throughout their growth cycle. Factors affecting yield are variety (7), planting date (14), tillage and fertilizer management, timing and amount of rainfall (or irrigation), crop rotation, and pest control. A deficit of water prior to flowering does not have much of an impact on yield. Water deficits during reproductive phases of growth effect greater yield reductions. Debate continues as to which reproductive phase is most affected by water deficits. Daily soil water can be modeled (24) where inputs are available for solar radiation, wind speed, temperature, humidity, and precipitation.

Extreme high temperatures can have a detrimental affect on yields. The affect may be variety specific in that the avoidance of heat stress through evaporative cooling may vary among varieties according to hereditary characteristics and canopy architecture. Temperature data can be used to form an agrometeorological stratification of possible sites for soya bean production. For instance, at the high SLU location, the number of days \( \geq 35^\circ C \) is 3 on average and 75 per cent of the years have 8 or fewer days with such high temperatures. The low SLU location experiences 23 days on average that have temperatures \( \geq 35^\circ C \) and only 5 per cent of years have 8 or fewer days. Clearly high air temperatures are more common at the low SLU location.
III.3 BIBLIOGRAPHY


