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Vision For R & D in Agrometeorology

Status, Preview & Vision

सत्यमेव जयते

Government of India
Ministry of Science and Technology
Department of Science and Technology
Earth System Science Division
New Mehrauli Road, New Delhi-110 016

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Drought Impact


Heat Wave - Damage to Poultry


Climate change studies


Agro forestry techniques


Rainwater harvesting


Technological input to Farmers

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Report of the

Expert Committee on Agrometeorology

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सचिव
Dr. T. RAMASAMI
SECRETARY

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विज्ञान और प्रौद्योगिकी मंत्रालय
विज्ञान और प्रौद्योगिकी विभाग
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FOREWORD

`Agrometeorology' is a multi-disciplinary science, concerned with all the physical and dynamical processes associated with the crop growing environment. Its primary objective is to discover and define such effects, and thus to apply scientific knowledge of the weather and climate to operational use towards sustainable development of agricultural production. Despite the technological advances that have taken place recently in the field of rainfed agriculture, the year-to-year variation in food production has remained in consonance with the weather variability in terms of onset of the monsoon and its behavior during the Kharif crop growing season. The all-India drought conditions during the years 2002 and 2004 demonstrated the need for strengthening the application of meteorological knowledge towards tactical decision-making to minimize the crop loss. The Department of Science and Technology (DST) also identified the need for monthly rainfall predictions at smaller regions instead of all-India seasonal rainfall forecasts and has facilitated intensification of research, development and training efforts in pursuing the science of Agrometeorology.

During the 8th plan period DST initiated an All-India Coordinated Research Programme on Agrometeorology with emphasis on crop-weather modeling and continued the support under their Monsoon and Tropical Climate (MONTCLIM) Programme. The study envisaged under the programme is further identified as one of the key components of the Indian Climate Research Programme (ICRP). The medium-range weather forecast based agromet advisory services provided to the Indian farmers need location-specific and crop- specific scientific results for appropriate guidance. The present document on "Vision for R & D in Agrometeorology" is a part of the report of the Expert Committee on Agrometeorology' which provides the details of multi-disciplinary scientific issues to be undertaken towards achieving sustainable agricultural production in the country.

I congratulate all the members of the Expert Committee on Agrometeorology in particular Prof. P.S.N. Sastry, the Chairman, and Dr. P. Sanjeeva Rao, Member-Secretary, for putting sustained efforts to promote the use of meteorological information in sustaining agricultural production. I feel that more concerted efforts are essential to realize the Vision by 2020, in the 11th plan period (years 2007 to 2012) by all the concerned departments and organizations in India to meet the demands of the Indian farmers. The DST shall continue to provide new thrust and a holistic approach for stimulating the science of Agrometeorology.

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PREFACE

Weather and climate are the integral parts of the agricultural production system that is reflected in the dependence of the country's economy and food grain output on monsoon activity year after year. Weather is an important component not only for crop production but also for horticultural crops, livestock, fisheries, forestry and other areas such as transport, storage and marketing of agricultural products.

Since the introduction of agrometeorological activities in the 1930s in India on the recommendations of the Royal Commission on Agriculture, several advances have been made on the technological, computational and communication fronts. Simultaneously, introduction of short duration hybrid plant varieties in the country's agricultural practices have brought into focus the need for strengthening short and medium range weather forecasts and studies on short period weather effects on on-field agricultural activities.

Growing concern for food security, impact of Climate Change and Variations on agriculture, impact of impending global warming on cropping patterns and agricultural output, air pollution effects on agriculture, need for development of month to seasonal weather forecasts for agriculture, recurrence of disastrous and aberrant weather systems visiting some part of the country or the other, all of which have a major agrometeorological element, has received government's attention.

Realizing these needs, in the 1980s research, teaching and extension programs in agrometeorology have been expanded in the country by the Government of India through starting Departments of Agrometeorology at State Agricultural Universities for human resource development, promotion and organization of several in-service training programs at post graduate level, starting of Weather-based agroadvisory services to the farming community, a Centre for Advanced Studies in Agrometeorology and an All India Coordinated Scheme on Agrometeorology with 25 centres covering the different agroclimatic regions in the country. Since the 1990s, creation of a National Centre for Medium Range Weather Forecasting, establishment of Agro Advisory Service Units in all the agroclimatic regions in India for utilizing these forecasts for advising agricultural operations, execution of a Land Surface Processes Experiment in the Sabarmathi river basin, establishment of a Data bank in Agrometeorology has further given a fillip to the agrometeorology programs in the country. In all these activities, Department of Science and Technology (DST), India Meteorological Department (IMD), Indian Council of Agricultural Research (ICAR) and State Agricultural Universities (SAU_s) are directly involved, and with cooperative support from National and International linkages, the necessary infrastructure has been created.

Programs in agrometeorology had been periodically reviewed, but in view of the ever-increasing demand for value addition to agrometeorological information and other agrometeorological services for agricultural operations, the DST has constituted a committee to review the status and prepare a Vision document in Agrometeorology for the coming two decades. The committee has made efforts to review the status of agrometeorological services in the country and elsewhere in the world (chapters 3, & 4), achievements in the country (chapter 5), assess 'user requirements' through circulation of a questionnaire to concerned institutions, subject matter specialists in the country (chapter 6) and feedback received from the farming community through the agroadvisory program. For better appreciation of the issues involved, a brief discussion, as a preview to thrust areas (chapter 7), is included as a prelude to the Vision paper (chapter 8). All these, constitute the vision document.

An "***Integrated and holistic approach to Agrometeorology***" has been chosen as the theme for the next two decades. It is time that activities in Agrometeorology are integrated with major sister disciplines in agriculture, such as physiology, soil science, agronomy, crop protection and crop breeding for developing the principles of management through interactive and interdisciplinary mode which had been the weakest link in the past.

The committee wholeheartedly acknowledges the assistance received from several National Institutions concerned with operational agriculture and individual experts who have responded to our queries. The committee members are grateful to the Secretary, Department of Science and Technology, for giving this opportunity to review agrometeorological activities in the country and prepare a vision document. Timely assistance received from the Earth System Science Division of DST at various stages in processing the questionnaire, arrangement of committee meetings and other secretarial and financial assistance is acknowledged.

(P.S.N. SASTRY)
Chairman
Expert Committee on Agrometeorology

Vision For R & D in Agrometeorology

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VISION FOR R&D IN AGROMETEOROLGY

Chapter 1

PREAMBLE

Agrometeorological Research in agricultural research institutions in India had its beginning in the earlier years of the 20th century with research efforts on evaporation, soil temperature, soil moisture and soil gases, at the then Imperial Agricultural Research Institute at Pusa, predecessor of the present Indian Agricultural Research Institute (IARI) at New Delhi. Consequent to the recommendations of the Royal Commission on Agriculture, the activities in this discipline took a concrete shape with the establishment of the Division of Agricultural Meteorology in the year 1932 in the offices of the India Meteorological Department (IMD) at Pune. This paved the way for formulation of an All India Crop Weather Scheme in 1945 in collaboration with the Indian Council for Agricultural Research (ICAR), Indian Central Cotton Committee and Indian Central Sugarcane Committees. A network of agrometeorological observatories was started at the State agricultural farms, which also carried out field experiments under the crop-weather scheme for developing crop-weather relations. Major crops like rice, wheat, sugarcane, and cotton, raised under rainfed conditions were covered by this scheme. Issue of farmers' weather bulletins was initiated. The Agromet division at Pune also participated in the SITE Program and later, an Agromet Advisory Service bulletin was started at 17 centres for the farming community.

During the 1970s the status of agrometeorological studies in India were reviewed by the National Commission on Agriculture constituted by the Government of India which recommended delineation of the country into Agroclimatic zones taking yield and spread of crops into consideration, and strengthening of the research and human resources development through establishment of Departments of Agricultural Meteorology in the State Agricultural Universities (SAUs). In the year 1983, under the VI Plan, the ICAR initiated an All India Coordinated Research Project in Agrometeorology (AICRPAM). Under a UNDP program, a Centre for Advanced Studies in Agrometeorology (CASAM) was established at the College of Agriculture, Pune functioning under the Mahatma Phule Krishi Vidyapeeth, Rahuri, Maharashtra for strengthening of post graduate teaching & training. The ICAR Quinquennial Review Teams reviewed the program of research and other activities in Agricultural Meteorology in the country twice, once in 1992 and again in 1998.

Department of Science and Technology (DST), Government of India installed a super computer and established the National Centre for Medium Range Weather Forecasting (NCMRWF) with a major component for services to the agricultural community. Five-day weather forecasts were put out and a weather-based 'Agromet Advisory Services' scheme was initiated by the year 1991 on a trial basis. The ICAR, the IMD and SAUs are active partners in this ongoing scheme. Agrometeorological Advisory Service Units (AASUs) are to be opened at 127 NARP (National Agricultural Research Program, ICAR) centres located in the different Agroclimatic zones. Presently, 107 AASUs are functioning and receiving medium range weather forecasts once / twice a week and formulating weather-based agro-advisories with local expertise which are being finally disseminated to the farming community through various mass media and personal contacts. On the basis of efforts made by various organizations and scientists in the field of agrometeorology, regular weather forecasts (2-day outlook & medium range weather predictions) are being used by agricultural scientists to provide local advisory to farmers. This scheme is reviewed annually, which provides a periodical feed back. This service has created awareness among farmers about benefits and use of weather–based information and advisories for their field operations. Presently economic impact of these advisories is under study.

Meanwhile, the Planning Commission was also concerned about drought occurrence in the country from time to time and started Agroclimatological Regional Planning Project and started an Agroclimatic Regional Planning Unit (ARPU) at Ahmedabad in 1988. This institute had been carrying out natural resource and socio-economic analysis for planning economic strategies for diversified agriculture encompassing horticulture, dairying, poultry, fishery, livestock, agro-processing and crop husbandry, on the basis of Agroclimatic zones and sub-zones. The National Bureau of Soil Survey and Land Use Planning (NBSSLUP) of ICAR with headquarters at Nagpur, took up delineation of Agro-Ecological zones supplementing the Agroclimatic zones to include information on soil-physico-chemical characteristics for determining land suitability for cropping systems and land use planning in the country.

The DST has been funding research projects in agricultural meteorology since the establishment of NCMRWF under the Monsoon and Tropical Climate and Agrometeorology Programs with focus on crop-weather modeling, impact of climatic variations and change on agriculture and also in support of the weather-based agro advisory services. Projects seeking to explore new methodologies and new frontiers of research in Agrometeorology are also supported. Several projects related to agrometeorology completed their tenure and a few programs are in the pipeline. A major step has been the creation of Data Bank in Agrometeorology by DST in cooperation with ICAR at the Central Research Institute for Dryland Agriculture (CRIDA), Hyderabad.

The DST having been concerned about the impact of Climatic variations at different time scales and Climatic Change, El Nino and Southern Oscillation (ENSO) and Global warming effects on monsoon activity and drought occurrence, which have significant influence on Agricultural productivity, decided to get status of agrometeorological activities in the country reviewed and also formulate a comprehensive Vision for Agrometeorology, for the next two decades—year 2020. An Expert Committee with Prof. P.S.N. Sastry (Principal Scientist (Retired), Agrometeorology, IARI, New Delhi) as Chairman, was constituted in 2001 with the following terms of reference.

1. To review the recent advances in Research, Development and Training in the meteorological applications in agriculture
2. To document the significant achievements in the field of Agricultural Meteorology and their potential in sustaining agricultural production in different agroclimatic conditions of India
3. To suggest thrust areas for strengthening Research, Development and Training in Agrometeorology in India
4. To formulate short-term and long-term action plan for implementation by the concerned organizations / institutions in India
5. Any other related items which the Committee may like to include.

The Committee met for the first time in April, 2001 at DST, New Delhi and decided on the modalities to be followed for preparation of the status paper and vision document. It was decided to circulate questionnaires to different research institutions in the country that are concerned with the research output from agrometeorology / agroclimatology. It was also decided to invite status reports from subject matter specialists on specific topics; individual scientists were identified and approached for this purpose. A general outline of the probable contents of the proposed document was also discussed at the first meeting. Also, it discussed in detail the status on animal-climate relationships and agromet aspects of remote sensing in agriculture presented by the scientists from the Indian Veterinary Research Institute, Izzatnagar, National Dairy Research Institute, Karnal and Space Application Centre, Ahmedabad.

Second meeting of the Committee was held in September 2001 at Gujarat Agricultural University campus at Anand to take stock of the progress of the committee's work and also some of the status reports received from experts on specific topics till that time. Presentations were made at this meeting also on "Climatic water balance", "Agromet Advisory Services", "Integrated Pest Management and Weather" by scientists from Andhra University, NCMRWF and NCIPM. Meanwhile, tentative lists of thrust areas for the 10th plan document, mid-term thrusts and for the rest of the period upto 2020, which are to become part of the vision document were identified.

Questionnaires were framed and circulated widely to the ICAR Institutes, ICAR Coordinated Project Centres, State Agricultural Universities and individual experts dealing with several aspects of agriculture which have concern with influence of crop-climate relations including animal husbandry, dairying, horticulture, livestock, poultry, plantation and commercial crops. Response to the questionnaire has been overwhelming and encouraging with positive suggestions, though it took some more efforts and time than expected to obtain them.

Most of the work of the Committee was carried out through correspondence. Review of the activities in agricultural meteorology and sifting through the replies to questionnaires occupied some time. A final meeting was held on 4-5 August 2003 at CRIDA, Hyderabad to consider the draft report. Further suggestions were incorporated into the report and the Committee approved the same. Cooperation from the Heads of several institutions, SAUs, individual experts who had provided their inputs through the response to questionnaires and status reports, is gratefully acknowledged by the Committee.

In this document are included, Executive summary, note on Agrometeorological support to services in agriculture, Agrometeorological Services in India, an appraisal of response to questionnaires, status of activities, preview of thrust areas, and Vision 2020 for Agrometeorology with suggested action plan.

A kaleidoscopic view of activities in Agrometeorology in India, since the 1920s has been compiled in a visual form, separately as part of the activities of the Committee.

EXECUTIVE SUMMARY

The Expert Committee on Agrometeorology constituted by the Department of Science and Technology (DST) for preparing status report and vision document in Agrometeorology for the next two decades, after eliciting user requirements in the country and deliberating on the points of reference made to the Committee, due consultation with scientific community, review of research publications and progress reports and discussion meetings, makes the following observations and recommendations.

"**Integrated and holistic approach in agrometeorology**" has been set as the theme for the coming decades. Integration of results from past efforts in agroclimatology with (a) support from basic and applied research to fill up gaps (b) adoption of new approaches to analysis (c) utilization of modern tools like remote sensing, simulation modeling, GIS technology and communication systems, is expected to result in framing of more realistic weather-based agroadvisories and render value added services for day-to-day agricultural operations, and move towards maximization of agricultural produce in the next two decades.

Satisfactory progress has been observed in research, education and extension fronts in the field of agrometeorology since the activities were initiated in the 1930s on the recommendation of Royal Commission for Agriculture for India. Significant achievements include creation of a network of Agromet observatories, Climatic database, Development of models for crop yield forecasting, Climatic classification for agriculture, Rainfall characterization through probability statistics. Starting of Agroadvisory units, Creation of a Databank for Agrometeorology, All India Coordinated Research Project in Agrometeorology, Weather-based Agroadvisory Services, Creation of facilities for in-service training, Establishment of Departments of Agrometeorology, National and international cooperation through joint programmes.

For the future, phenology-based agroclimatic characterization, In-season monitoring of crop-weather situation on regional scale, Introduction of "Agro-weather charts" for day-to-day work at nodal agricultural research centers, Innovative approaches to agroclimatic analysis for identifying optimum combinations of crop-weather parameters under various scenarios of impact of Climatic Change/ variations on cropping patterns and productivity, are recommended for induction into agrometeorological activities.

Organization of crop data collection and on-line transmission from a network of crop observation sites is recommended (a) for preparation of "Agro-Weather Charts" (on the analogy of synoptic weather charts) including information on both crop conditions and weather on a single map (b) as an aid in preparation of weather-based agroadvisories and (c) to relate satellite observations validated periodically by ground truth (d) use of dynamic simulation models and GIS technology for monitoring and forecasting crop growth and (e) for developing regional/ zonal-level strategies and operations in agriculture. This should be a routine activity at all nodal agricultural research centres.

These would be of practical significance to agricultural operations ensuring both local and regional monitoring of each of the crop species during a current season. "Agroclimatic maps" using *time-series data* and "Agro-weather maps" using current weather in a crop season could be the future activity. For effective implementation, and to provide 'value added services' in Agrometeorology, it is recommended that every State Agricultural University and Crop/ Veterinary and livestock Research Institutes of ICAR may take expeditious steps to create Divisions of Agrometeorology /Agroclimatology wherever they are not in existence.

Development of models for early warning systems to cover all types of stress (cyclonic systems, drought, floods, pest/diseases, air pollution, advective heat transfer, cold and heat waves) caused due to aberrant weather is a priority area for support.

Compilation and collation of agrometeorological information and definition of agrometeorological threshold values for each of the major crops from available literature supported by laboratory and field research to fill up gaps in such information. This is an essential requirement for any analysis.

Agrometeorological information generated over the past several decades is yet to be compiled for each of the crops and weather thresholds defined which would be a benchmark for any type of agroclimatic analysis. This is a priority requirement. Compilation of reports through working groups or individual scientists and their publication with time bound project support is recommended.

Studies on "Impact of Climatic Change and Variations" on crop planning and productivity need to be intensified. Coordination with other organizations (both national and international), is desirable.

Instrumentation for agrometeorology is one area that deserves urgent attention. Not a single instrument is commercially manufactured within the country and mostly they are imported. Establishment and promotion of indigenous manufacture for weather sensors, and other equipment used in agrometeorological research and creation of calibration and service facilities is a high priority area. At present we are entirely dependent on imports, creation of such facilities would lead to import substitution and avoiding breaks in the observations and database.

Development and use of crop-weather simulation models and EXPERT Systems for day-to-day weather-based agricultural operations using real-time data is an area that needs urgent attention. Comprehensive strategy for achieving this objective is required.

Development of risk management strategies (for drought, flood, heat-wave, cold-wave and other aberrant weather situations, cyclones, thunderstorms, hailstorms, etc.) based on probabilities of weather events derived from historical data integrated with current weather events and forecast weather is a priority area for action.

Microclimate studies have not received the attention they deserve. Being significant to determine energy balance of crops/animals, glass/plastic houses, storage structures, and animal housing, air pollution, effectiveness and economic application and dissemination of insecticides, studies in this branch should be initiated in the next couple of years and intensified gradually over the next decade.

Intensification of research efforts on influence of weather/climate on growth and development of plantation crops, spices (clove, cardamom, pepper, etc.), commercial (viz., tobacco, rubber, tea etc,.) horticulture (fruits, flowers and orchid) and herbal crops which have received less attention in the past. Creation of agrometeorology divisions at these institutes is recommended to study thermal, moisture, pest/disease, product quality during and after growth (storage) as influenced by weather.

Promotion of studies on animal-climate and fisheries-climate interactions (including dairy animals, sheep, goat, birds and poultry, inland fisheries) and influence of environment on the output products is recommended. This is an unexplored area from the operational point of view e.g., prediction of milk/egg production which is dependent on environmental conditions.

Weather effects (thermal and moisture regimes) with respect to maintenance of quality of agricultural products during storage, transport and marketing of the products are important for investigation on priority.

It is gratifying to note that present agrometeorological research activities include support research programs in application of remote sensing in agriculture, required in tackling field problems —agricultural drought, flooding, disaster management etc., Agroadvisory activity with NCMRWF, AICRPAM, SAUs would be the first beneficiary of such programs. It is notable that SAC, NRSA, IMD and ICAR institutes are moving in this direction and have evolved several collaborative programs. These need continued support for the inter-disciplinary activities involved.

As part of Human Resource Development, action has to be taken to establish Departments of Agrometeorology in all the State Agricultural Universities and National Institutes dealing with Agriculture, as recommended by National Commission on Agriculture as early as 1976. Strengthening of education and in-service training in Agricultural Meteorology is a priority area. Introduction of Diploma and Vocational certificate courses on operational applications of Agrometeorology should also form part of this program.

Standard textbook literature in agrometeorology is practically non-existing. Production of textbooks, manuals and guidelines detailing procedures for observation, maintenance and upkeep of instruments and agroclimatic analysis may be encouraged through liberal project support by concerned organizations.

International collaboration and exchange programmes in interdisciplinary areas of Agrometeorology had been beneficial, but are few and far between. These need more active support in all the three areas of teaching, research and extension related to Agrometeorology / Agroclimatology.

Vision for next two decades is that with "**Integrated and Holistic Approach in Agrometeorology**", at the end, Agrometeorological Services for day-to-day agricultural operations would have contributed their might towards achieving food security for the country and bringing about improvement in rural livelihood. Self-reliance in several areas of research, education and extension in agrometeorology would be achieved, at the same time keeping excellent national and international linkages.

AGROMETEOROLOGICAL SERVICES TO AGRICULTURE

Agrometeorology is the scientific study of influence of weather on crops, animals, fisheries and other species related to farming. Several agricultural activities from seedbed preparation to harvest, storage, marketing and transport are influenced by weather. Study of hydrological cycle in relation to crop husbandry had thus drawn the attention of researchers since early times. The discipline also includes studies on animal husbandry-climate relationships, fisheries, livestock, and poultry as influenced by weather.

Both, favorable and unfavorable effects of weather, their forecast and relevance in the field of agriculture are traditionally known to Indian farmers, since times immemorial. The folklore, rural proverbs and thumb rules generated for anticipating local weather conditions by farmers over generations of experience, some of which hold good even today from the scientific point of view, is a reflection of the awareness of the farming community on the influence of weather on crop production and animal husbandry.

Role of Agrometeorology in Agricultural Production Systems

Scope of Agrometeorology

As early as the year 1898, Edward Mawley, President of the Royal Meteorological Society, stated that "There are few sciences so intimately connected with each other as Meteorology, Agriculture and Horticulture". Agrometeorology thus deals with quantitative relations between weather, productivity and management. Around the year 1921, R.H. Hooker, the then president of Royal Meteorological Society, suggested the use of statistics to correlate yield with weather variables. Subsequently this approach was adopted by several researchers, and it is no surprise to note that even till this day, more of crop-weather interactions are expressed in terms of regression analysis in one form or the other. In the year 1966, Austin Bourke a renowned scientist, expressed the scope of Agrometeorology at a symposium on Agrometeorological Methods organized by UNESCO at Reading, U.K. as follows: "The task of the Agrometeorologist is to apply every relevant meteorological skill to helping the farmer to make the most efficient use of his physical environment, with the prime aim of improving agricultural production, both in quantity and quality....". This sufficiently explains the scope of Agrometeorology and the objective of its study for rural development in the country.

As to the significant recognition received by the discipline, the World Meteorological Organization (WMO) of the United Nations, under its Climate Research Program has set up a Division of Agrometeorology and a Commission for Agricultural Meteorology (CAgM) to coordinate the programmes world over with member countries. The routine activities of the Commission include organization of working groups for bringing out technical and scientific reports on crop-weather relations and updating them from time to time, standardization of procedures and organization of international symposia to make latest research results and field experience available to one and all.

The purpose of the WMO Agrometeorology program formulated by the CAgM in the draft for the 5th Long Term Plan (LTP) is stated to be "...to help develop sustainable and economical viable agricultural systems" and "...to improve production and quality, reduce losses and risks, decrease costs, increase efficiency in the use of water, labour, energy, and conserve natural resources, combat drought and desertification.....". This statement reflects the role played by Agrometeorology in diverse facets of agricultural activities, from sowing to post harvest and market operations. In the Indian context, in any given year, its economy continues to be a gamble in the intensity of the monsoon activity, (though, partly it has been insulated through expansion of irrigation facilities and management of food stocks) and hence the keen interest in monitoring, forecasting and understanding crop performance in relation to variable weather each year.

Climate, weather and agricultural operations:

With reference to practical agriculture, one would like to know answers to the queries such as:

What are the regions and seasons where climate is suitable for raising crops with respect to the different species? What would be the yield potential? What weather factors promote pest/ disease growth into an epidemic and at what growth stages of crops? When could one expect sowing rains? What is the probability of field workable days during the rainy season? Can rainfall alone, if so, how much and in what season, could meet water requirements of crops? When should the crop be sown? When could one expect flood or drought, with what intensity and for how long? What are the temperatures, which are conducive to retain keeping, color and eating qualities of fruits and vegetables and for how long? These are only a few typical questions cited here as an illustration about the various facets of agricultural activities where information on weather and its scientific study with reference to crop or animal husbandry is essential for providing advisories based on anticipated weather. It is through the study of Agrometeorology that one could provide answers for these.

There are two dimensions to the study of influence of weather on crops / animal husbandry. One is the assessment of long term influence and expectations, which constitutes the study of "Agricultural Climatology" or in short, 'agroclimate'. This is based on long term averages of weather elements and their relation to crop growth and development.

The second one is the real time information on both climate and weather employed for farm decision-making for purposes of advance planning and day-to-day operations. A few such applications in practice are listed below.

Climate (long-time average weather, probabilities)	Weather (Current weather actual values)
Choice of farming system and choice of crops	Timing, land preparation, date of planting and area under crops
Choice of optimal variety	Choice of alternate variety
Choice of farm equipment	Actual use of equipment Day-to-day operation
Choice of irrigation	Timing and amount of water release
Likelihood of pest/ diseases	Actual occurrence, population level, Management options and schedules

These activities are listed only for illustration. It is obvious that Agrometeorology can provide several services to practical agriculture and in-season management. Such services include generation, analysis, and dissemination of information and advisories. Some of them are:

Quantitative information (maximum, optimum, minimum) of the relevant weather parameters for different crops related to (a) factors like water requirements that define *potential production* (b) factors like water balance that *limit production* and (c) factors like pest /

disease- weather that *reduce production.*

Information on weather factors that help with the breeding and selection of varieties adapted to the length of the growing season, rainfall, drought probability, sunshine etc., expected to prevail at different growth stages.

Information on availability of suitable environmental conditions for practicing multiple or intercropping systems for optimal utilization of the natural resources and inputs.

Climatic, probability and forecast information for the planning of irrigation systems, risks of water deficiency, optimization of water use efficiency, information for day to day irrigation scheduling, pest-disease control operations and, optimum time for harvesting etc.

Agrometeorological information thus has to cater to farmers, policy makers, extension and research workers both for long-term planning and day-to-day agricultural operations. The data collection, collation, analytical procedures, and presentation have wide variety and any single general format cannot be expected to provide the required service fully and satisfactorily. Unlike the climatic analysis, this involves generating a wide variety of databases, analytical procedures and their standardization, presentation of results, and their interpretation depending on a specific objective with large infrastructure. In view of the high coefficient of variability observed in the weekly rainfall, shifting positions of tracks of depressions, cyclones and western disturbances during the cropping seasons in the country, long-term averages rarely represent the actual conditions obtaining in any given season. Thus the development of a wide variety of strategies through Agrometeorology, based on crop-weather relations can render better service to agriculture.

The Issues Concerning Agrometeorological Research in Relation to Operational Agriculture:

The DST (NCMRWF) brought out a review document on "Development of Agrometeorology in India" in the year 1990, which included a comprehensive but brief account of the status of agrometeorological activities in the country since the 1940's. The document reviewed the results obtained upto that time in the field of agrometeorology and it provides information on the activities at several national institutions, state universities and other organizations which included research, teaching, extension and technical support services in this discipline along with some issues concerning future research thrusts. Proceedings of two more workshops (i) User Requirements for Agrometeorological Services organized at Pune by IMD and WMO in 1997 and (ii) Agrometeorology in the 21st century-Needs and Perspectives organized at Accra, Ghana by WMO in 1999 provide an insight into the issues concerning agrometeorological research and services in relation to operational agriculture.

Practices followed in several countries in the world, their experiences and future outlook were reviewed and discussed at these workshops. Issues concerning India are not different today and these three documents cited above provide a wealth of information on the prospects and direction in which agrometeorological activities should take shape to meet the challenges to be faced during the 21st century.

Some of the conclusions of the workshop at Pune, which have relevance to the present vision document, are given below:

The main problem was recognized to be *"Inadequate information, insufficient methodologies, resources and poor awareness of user needs"*

The main causes identified for this state of affairs were:

Lack of:

(i) In-depth impact studies (ii) Appropriate feedback
(iii) Adequate training, and (iv) Effective coordination.

Cause-effect factors identified by them in this connection included:

Lack of:

(a) Specific crop phenophase-wise weather study
(b) Knowledge about crop and variety specific weather interactions,
(c) Changing and diverse needs of users, and
(d) Sensitization

3.1 Recommendations from the International Workshops:

Most of the existing agrometeorological services being considered inadequate there is tremendous scope for improvement. User requirement being the key factor, one of the causes of this inadequacy identified is the lack of proper understanding and communication between the 'providers' and 'users'.

Greater emphasis should be placed on human resource development to enable better service provision.

Simple but accurate and reliable, affordable methods and techniques should be developed to render customized information and advisories.

National interdisciplinary coordination committees should be formulated to enhance cooperation among users, agrometeorologists and policy / decision makers.

The network of agrometeorological observation stations should be improved/ enhanced in order to provide location and crop specific advisories e.g., Livestock, pastures, agro-forestry, urban agriculture etc.,

Salient points from the workshop on "Agrometeorology in the 21st century—Needs and Perspectives" held in 1999 by WMO.

Recommendations: One of the main issues to be tackled in the new millennium would be a collaborative effort between WMO, FAO, IARC and NARS to lay out operational-scale long-term interdisciplinary field studies at well-defined benchmark locations in order to evaluate the needs for agricultural and meteorological data for system modeling, transfer of technology and technical back-up support required by the farming community at large, to sustain agricultural development.

Yield predictions will be more accurate when based on models developed with *observed rather than estimated data* especially for tropical regions.

Conventional empirical approaches are considered inadequate for addressing the complexity of the interaction between global climate, regional weather variability, decision-making, agricultural productivity and economic responses.

The problem of *lack of reliability* and consequently *lack of trust* in weather forecasts exists in many countries.

ENSO predictions combining GCMs with an Ocean model as an extension on long-term weather forecasting for operational purposes is proposed. Estimation of their consequences for agricultural production is advocated.

Design of management and manipulation techniques for improvement in the microclimate of cash crops such as rubber, oil palm and coffee for improving their growth conditions.

At the end of research chain, *on-farm validation* of new approaches and technologies that take traditional and more recent local knowledge into account are needed— most of all, for the management of agricultural productivity.

Agrometeorology can form part of the ecosystem approach in the context of Convention on Biological Diversity Research for the benefit of the management, conservation and rehabilitation of critical resources in research activities springing from the Climate Change Framework; also, socio-economic effects of variability should be included.

In several developing countries, there is virtually no adoption by small farmers of improved soil and crop management technologies recommended by research and extension system.

These deliberations on the 'Needs and Perspectives' in agrometeorology / agroclimatology point out future action for (a) concentrating efforts on making weather forecast more reliable and accurate using model approach (b) use of real-time data for agricultural operations (c) microclimate manipulation in cropped fields (d) user requirements as first priority (e) advisories to be user-oriented and more specific, with practicable and affordable agricultural operations to *render customized information and services* (f) on-farm validation of new technologies that are recommended in the advisories and (g) human resource development.

It need not be emphasized that an improved weather-based advisory can follow only an improved weather forecast whether it is of short, medium, seasonal or long range in time.

3.2 Developments in Agrometeorology: Current Status

As mentioned earlier, it was in the 1920's that efforts had been made to relate crop performance to weather with particular reference to rainfall distribution and temperature through application of statistical procedures. Agrometeorology evolved as a discipline at this time. During the next two decades, in absence of instrumentation, efforts were concentrated on estimation of solar radiation and its components being the main source of energy for crop production. Rapid strides in development of electronics paved the way for sophisticated instrumentation for utilization in agromet studies. With the advent of PCs, microprocessors in the 70's it has become possible to gather vast database direct from the field crops sitting in the laboratory all the 24 hours, throughout the year, where even until the early 60's, recourse had to be taken to time and manpower consuming methods of manual observations within the cropped field. Even in future, manual observations will continue to play their role in data collection in cropped fields.

Agrometeorology has contributed substantially to the management of irrigation schemes.

In several countries, for the past four to five decades, the extensive research of methods for calculating potential evapotranspiration has become the basis for managing irrigation scheduling at planning and field level both under conditions of unlimited and restricted water supply. By matching water application to crop water requirement, agrometeorological information is at the heart of cropping systems planning for attaining high water use efficiency.

Currently, we are all aware how further rapid development in the observation and communication modes through satellites, information technology and GIS techniques, have paved the way for gathering and disseminating information and expertise on-line from anywhere to anywhere in the world. Naturally, in the field of agrometeorological services to agriculture all over the world, these facilities are currently employed.

The other recent development in providing service to agriculture based on agrometeorological information is the application of crop-weather models using dynamic simulation approach, remote sensing techniques through satellite technology and advanced communication facilities.

Crop growth simulation models using dynamic approach are playing an important role at different levels of application ranging from decision-support for crop management at farm level to advancing understanding of sciences at research level. Agrometeorological information is extensively used in their formulation and application. Strategic applications (models are run prior to planning of a crop to evaluate alternate management strategies), tactical applications (models are run before planting of a crop or during a current crop growing season); these two strategies provide information for decision-making by either a farmer, consultant, policy maker and other persons directly involved in crop management and production. In the forecasting application, model is run prior to planting of crop during the growing season. The main objective is to predict yield, which can be used at a farm level for marketing decisions or at a government level for deciding on policy issues and food security options.

Impact of climate change and climatic variability on agriculture is being assessed under different expected scenarios using simulation models. Several studies have been conducted in our organizations in the country suggesting possible impact on agricultural productivity. These simulation models are being used with General (global) Circulation Models (GCM) for prediction of atmospheric conditions and formulation of weather forecasts for operational agriculture. The studies include impact of assumed increase/decrease in temperature, rainfall, evaporation on productivity of crops in the different regions under expected scenarios due to climatic variations.

Dynamic simulation models are being used to delineate agroclimatic zones as part of systems analysis approach, and for estimation of moisture availability and depletion patterns in the soil using limited crop, soil parameters, as addends to extensive agrometeorological information needed for running the model. With calibration and verification of such models, these are used as service tools in monitoring drought stress or moisture availability in the soil for yield assessment.

Another aspect receiving attention in several countries is the human resource development. A feature observed in several developing countries as assessed by the WMO is the lack of trained personnel in agrometeorology at various levels. A few reasons generally cited in this connection with respect to these countries by WMO are:

The number of graduates studying agricultural meteorology is small in comparison to other graduate disciplines. The potential user groups of agrometeorological information

(Agronomy, Entomology, Plant Pathology, Horticulture etc.,) lack sufficient understanding of agricultural meteorology in order to make use of the training provided.

Lack of systematic follow up and of evaluation of post-training performance, especially after the in-service training

Poor selection of candidates for agricultural meteorology training programs: (selection is often made on the basis of seniority or personal contacts rather than relevance or objectivity).

Human resource development (HRD) is one area in which more efforts are required in the future to provide training facilities in the several facets of the discipline of agrometeorology, which touches almost all activities of agriculture.

The United Nations Conference on Environment and Development (UNCED) which took place in Rio de Janeiro, Brazil in 1992, and the three international conventions viz., The United Nations Framework Convention on Climatic Change (UNFCC) the Convention on Biological Diversity (CBD) and the United Nations Convention to Combat Desertification (UNCCD), which have a bearing on sustainable agriculture, had emphasized on the development of weather-based strategies which involve agrometeorological activities. Some of the areas where Agrometeorology will continue to have a significant role to play are:

Development of early warning and advance planning for periods of adverse climatic variation in a form suited for practical application by users at all levels including especially, the local population.

Strengthening drought monitoring, preparedness and management strategies, including contingency plans at the local, national, sub-regional and regional levels, which take into consideration seasonal to inter-annual climate predictions.

Development of sustainable irrigation programs for both crops and livestock husbandry, improvement and strengthening of Agrometeorological network.

Development of new sources of data for operational Agrometeorology.

Improved understanding of natural climate change and climate variability.

Promotion and use of monthly, seasonal to inter-annual climate forecasts for agriculture.

Establishment and strengthening of early warning and monitoring systems.

Promotion of GIS and remote sensing applications and agro ecological zoning for sustainable management of farming systems, forestry and livestock.

Use of improved methods, procedures and techniques for dissemination of agrometeorological information.

Development of agrometeorological adaptation strategies in cropping systems to climate variability and climate change.

Active application of models for phenology, yield forecasting at farm, local and regional levels.

There are several factors to be looked into for effective utilization of the various services that can be rendered using agrometeorological techniques as utility in management of agriculture and animal husbandry. Concerted and target oriented efforts are required to facilitate this by giving priority to these programs. Thus, Agrometeorology or Agroclimatology, as the nomenclature implies, do not merely relate to the study of weather or climate in relation to crop or animal husbandry. It has to provide the required services to the farming community based on both theoretical and practical relationships for carrying out timely agricultural operations such as sowing, irrigation scheduling, drainage design, pest and insect management through timely and economic application of pesticide and insecticide control measures at various growth stages. Harvest of crops, post harvest operations like storage, transport and marketing are significantly influenced by weather. Physiological, biochemical, metabolic reactions in the crop/animal growth and development systems are also highly influenced by the weather mostly by radiation, temperature and moisture.

Thus, the scope of studies in Agrometeorology covers a wide range of disciplines/ subjects- soils, biochemistry, agricultural chemicals, economics, engineering, plant pathology, entomology and several others in relation to practical agriculture.

AGROMETEOROLOGICAL SERVICES IN INDIA

Organization of Agrometeorological Activities:

Activities in the discipline of Agrometeorology in India started with the setting up a Division of Agrometeorology in IMD under the pioneering guidance of Dr L.A. Ramdas in the year 1932 on the recommendation of the Royal Commission on Agriculture. Agrometeorological observatories were set up and crops were raised with weather observations taken in the field attached to the observatories. In the years 1945-48, in collaboration with ICAR, Indian Central Cotton Committee and Indian Central Sugarcane Committee, a crop weather scheme was started at selected research stations all over the country, which functioned till 1970. These developments lead to the formulation of statistical crop-weather models and development of crop-weather calendars depicting crop conditions in relation to both current and normal weather. At the same time, weather services for the farmers were started in India. "Farmers' weather bulletins" and "Weather outlook" for 48 hours have been initiated and broadcast through the radio every day. These indicate onset of rains, rainfall duration, intensity of monsoon activity and possible occurrence of weather hazards like frost and hail. Later, these bulletins also included district-wise short-term forecast of weather and heavy rainfall or low/high temperature warnings and cyclonic weather warning to fishermen.

Another service called the 'Agrometeorology Advisory Service' was initiated by the IMD in collaboration with State Departments of Agriculture in 1983 functioning from 17 units located at major meteorological centers of IMD. Unlike the farmers' weather bulletins, the agromet advisories prepared in consultation with State Directorates of Agriculture, included information on weather, growth stage of crops and crop conditions and likely impact of weather for the next 3 days. Advisories also briefly indicated measures to be taken in case of pest and disease incidence.

During the year 1952 climatic classification of the country was initiated at the Andhra University, Waltair based on water availability conditions in the soil obtained through climatic water balance approach. This approach pioneered by Prof. V.P. Subrahmanyam has given rise to development of several useful indices such as the moisture adequacy index, moisture availability index which have become tools to monitor drought stress in crops using threshold values appropriate to the crop and its growth stage. The above climatic classification has laid a good foundation for agroclimatic characterization of the country and subsequently to agro ecological zoning at regional and taluk level by other organizations like the IMD, CAZRI, NBSS & LUP, NARP project under ICAR, and Planning Commission with several improvements. Agro-Climatic Regional Planning Unit (ARPU) initiated by the Planning Commission and functioning from Ahmedabad aims at providing "an interface between technology based growth and natural resource endowments" from a "perspective of agroclimatic regions" to ensure " consistency between the socio and eco-systems for sustainability".

Agrometeorological research units were started under ICAR in the mid sixties at CAZRI, Jodhpur and IARI, New Delhi. Postgraduate teaching in agricultural meteorology was also initiated at IARI. The National Commission on Agriculture in its report (1976) laid considerable stress on expansion of research and teaching in agrometeorology. An all-India Coordinated Research Project in Agrometeorology (AICRPAM) was started in 1983, presently functioning with CRIDA at Hyderabad as the headquarters. Started in two phases, twenty-five centers located in the different agroclimatic regions are functioning under this scheme today. Climatic characterization, crop-weather interactions, crop-weather modeling, weather effects on pests and diseases were taken up for study. Several crop weather models for yield and pest disease incidence in crops were developed using statistical approach and these are being utilized in providing in-season forecasts to the farming community and used in weather-based agro advisory bulletins.

Realizing the need for medium range weather forecasting and the availability of super computer facilities, a National Centre for Medium Range Weather Forecasting (NCMRWF) was established by DST in 1988. Its objectives include development of operational medium range (3-10 days in advance) weather forecasting capabilities and agrometeorological advisory services for 127 agroclimatic zones delineated by NARP. Till now, 107 centers have been established at State Agricultural University (SAU) Research Stations and ICAR institutes in various parts of the country.

Medium range weather forecasts issued by NCMRWF twice a week covering a period of 4 days are utilized by Agrometeorological Advisory Service Units (AASU) located at SAUs for preparation of weather-based agroadvisories, with recommendations indicating the required agricultural operations. In this process, the research centers of the AICRPAM are actively involved and most of them are co-located with them. The advisories are formulated after a group discussion among the subject matter specialists in agriculture and disseminated through the radio/ television, telephone and other media. Economic impact of these advisories is evaluated periodically and it has shown encouraging results in certain cases. Rainfall occurrence or non-occurrence has been forecast successfully (80-90%) and also the advisories lead to economic benefits in some cases.

This service has undoubtedly created awareness among the farming community about the advantages of prior information on the occurrence of adverse weather. It is recognized that these efforts need further improvement and encouragement from the sponsoring and implementing agencies.

Monsoon rainfall for the Indian subcontinent, being the most essential element for food production in the country, since the 1880s, attempts were made by the Indian meteorologists to develop long range forecast models for estimating total quantum of rainfall likely to be received during the southwest monsoon season over India. Several regional and global parameters and their occurrence prior to the onset of monsoon were correlated with the monsoon rainfall received in different years. Since the year 1991, a power regression model is being used with 16 input parameters for predicting the monsoon rainfall over India with reasonable success. Its validity for different sub-divisions of the country was studied at AICRPAM; subdivisions, where, the forecast had shown a high positive score have been identified. However, from 2003 changes have been affected to address mid-season corrections and forecast for four regions of the country. The parameters have been reduced to 10. The 10-parameter Power Regression Model uses 8 parameters already known in April and 2 parameters, which need data up to June-end. Since the forecast is available nearly a fortnight before onset of the monsoon rains, this evokes considerable interest among the farmers as well as economists and planners. Efforts are continuing to bring out further improvement to these forecasts and to estimate likely food grain production of the monsoon (*kharif* season).

The Economics and Statistics Directorate under the Ministry of Agriculture, the IMD, the State Departments of Agriculture, the IASRI, Crop weather watch group (Ministry of Agriculture) are all involved in reviewing and providing periodical estimates of food grain production during and after the *kharif* season. Such yield estimates are based on crop cutting experiments, input from the crop-weather models, rainfall situation, which are needed for formulation of economic policy, storage and marketing operations. These efforts are being supplemented by studies at CRIDA on estimation of annual food grain production based on relationship between monthly rainfall indices and Southern Oscillation Index. When substantiated further, these efforts could hopefully provide a tool for forecast of annual food grain estimates eight months in advance. This is further being evaluated with fresh data and when confirmed in the coming years, would be a major step forward. This is an activity, which is based on agrometeorological information.

Crop-weather models in the form of regression equations for prediction of yield, incidence and development of pest/diseases developed in the 1960s and updated from time to time are being utilized in the country at a few centers for providing in-season forecasts. Though location and crop specific, these have proved to be valuable in formulation of weather-based agro-advisories using medium range weather forecasts. Integrated pest management based on weather-indices is another promising area that is making headway.

Remote sensing applications in agrometeorology:

The other recent development in providing service to agriculture based on agrometeorological information is the application of remote sensing techniques through satellite technology following the advances made in our country in this field. Of particular significance to agriculture is the application of remote sensing techniques for agriculture in several of its operations. Since 1972, when this technique was used to identify coconut plants affected by root wilt in the Kerala region, we have come a long way in attaining capability of identification of crop cover, acreage estimation and crop yield assessment, drought stress, through development of vegetation index and other indices. This is an ongoing activity and is heavily dependent on ground truth, agrometeorological information and analysis. Space Application Centre (SAC), the NRSA, ICAR Research Institutes; IMD and Agrometeorological Units at the SAUs have constantly worked in collaboration.

Combination of the remote sensing technology with GIS technique is the other emerging area which has facilitated mapping of weather and crop information, flooded areas, drought affected areas, ground water availability, disaster management in cropped areas due to passage of cyclones etc., Pilot studies have shown the capabilities of assessment of the effect of inconsistency in irrigation distribution on crop performance through application of this technology. Several other possibilities exist and it is only our willingness to take the challenges and work in the direction of finding a solution that would provide the necessary application technology in the field of agriculture. In this context, the National Agricultural Drought Assessment and Monitoring System (NADAMS) and the CAPE/ FASAL programs are the best examples that could bring us nearer to managing the adverse effects of disastrous weather events. Climatologists, Agrometeorologists, Agroclimatologists and Agricultural Scientists have a significant role to play in relation to these programs.

Animal-climate interactions:

Domestic animals, poultry, birds and other livestock, depending on the species and level of productivity, have an optimal environmental zone and they must maintain within this zone for optimal growth, lactation and reproductive functions. Reduced performance under heat or cold stress is due to associated effects on thermal regulation, energy balance, water balance and endocrine change among other factors. Divisions of physiology and climatology are functioning at a few veterinary research centers such as the IVRI, NDRI, HAU, GAU, TNAU etc., Results of research at these centers show that the thermal aspect of climate can alter the animals' body temperature, heat balance, hormonal and water balance with resultant effects on growth, reproduction, milk and egg production. Several factors such as feed intake, feed utilization, milk production and its composition, reproductivity, all of them get affected by the microclimatic environment of the animal.

Comfort zones for cattle, buffaloes and other livestock have been experimentally determined but these are not being effectively utilized in assessment of the effects of actual weather conditions in the different seasons. As an illustration, exposure to heat at 36°C and 65% relative humidity for consecutively three days is known to depress milk production, feed intake in lactating cows. Such information can be effectively utilized for yield estimations and early warnings for heat stress, which prevails at the times of heat wave conditions over several parts of the country for a week or two. Sufficient interaction between climatologists with veterinary physiologists does not seem to have taken place since crop research and animal husbandry research remained as separate entities.

Action is in progress both by ICAR and DST to correct this situation and a few research projects have been approved for such studies. A national workshop on Animal-Climate interactions attended by both the Agroclimatologists and animal physiologists, sponsored by DST was held at IVRI in March 2002 and areas of common interest identified. The laboratory (psychrometric chamber) results generated in the past can be gainfully utilized by adapting and transforming them for application under field conditions, since output from animals and livestock including poultry are of economic importance and are affected by weather in the individual seasons.

Agrometeorological database:

The most basic and important activity needed, both for research and operational programs, in any discipline for scientific study is the generation of database. It is agreed by one and all that the availability of a proper database is a major prerequisite for studying and managing the processes of agricultural, forest, and livestock production. Building up of weather, soil, agronomic, pest/disease database is of the first priority.

Data on weather and climate:

Our country is fortunate in the availability of a vast database on climate maintained by the IMD since the 1880's. Rainfall series for several locations are available for more than 125-year period and one can take pride in such a possession. This is scrutinized, quality checked and processed as per the standards laid down by the WMO. A National Data Centre has been functioning at IMD, Pune and is considered as one of the best repositories of climatic data by the meteorological services all over the world. Under the crop weather scheme, IMD in collaboration with state agricultural research stations has collected crop-weather data since 1945. Data from about 200 agromet observatories, weighing (gravimetric) Lysimeter stations and dewfall recording stations are collected.

Data Bank in Agrometeorology:

Realizing the importance of building up a database on agrometeorology, an Agromet Databank facility was sponsored by DST since the year 1999 and is located at CRIDA, Hyderabad. Agrometeorological data from several projects functioning under DST, NCMRWF, AICRPAM, AICRPDA, ICAR Institutes and State Agricultural Institutes are expected to deposit experimental data with this data bank. Facilities for data processing including data archival, retrieval, quality check and other related features have been created and are in active operational mode. Efforts are on to create a website for facilitating online data supply to the user community.

Human Resource Development in Agrometeorology:

The success of any research and extension organization depends on the management of the human resources and, the field of agrometeorology is no exception. Since 1932 in-house training in the IMD has been available in this field on a limited scale. Presently, IMD offers training in agrometeorology at different levels – for observers of agromet stations to a 6-month core course for personnel of the SAUs and Departments of Agriculture.

The National Commission on Agriculture has recognized the necessity of initiating regular training in agrometeorology at graduate and post-graduate level at the SAUs, in view of the expanding activities in agrometeorology both in the country and abroad. The Commission recommended setting up of Departments of Agrometeorology in the SAUs for teaching, research and extension purposes in the discipline. Since its recommendations, made in 1976, efforts have been made to open Departments of Agrometeorology by ICAR and the Agricultural Universities. However, it had to be gradually phased in view of non-availability of trained personnel in the discipline. Presently, separate Departments of Agricultural Meteorology have been functioning in 9 Agricultural Universities.

Under the 4th plan scheme a unit of agrometeorology was started at IARI, New Delhi since 1968 as part of the teaching and research programs of the Division of Agricultural Physics. A Division of Climatology (non-teaching) was earlier started at the CAZRI to cater to the needs of research in Arid Zone Climate. Post-graduate programs in Agrometeorology leading to award of M.Sc., and Ph.D. degrees are pursued at these centers. Under the UNDP support, during the year 1988 a "Centre for Advanced Studies in Agrometeorology" (CASAM) was established in the College of Agriculture at Pune. Thus a few regular training centers at post-graduate level are presently available with limited number of seats. Apart from these, several short-term training programs in Agrometeorology had been conducted on specific topics in the nature of summer / winter schools, special training programs, SERC schools (DST scheme) and for the personnel of the AAUs (Agromet Advisory Units) functioning at the ICAR Institutes and SAUs.

International Exchange Programs:

Teaching, research and instrumentation facilities in Agrometeorology were also strengthened by ICAR under a INDO-USAID sub-project on "Strengthening Agrometeorological Research to Enhance Food Production" from June 1988 to June 1992. Under this program, 16 Scientists from SAU's and ICAR institutes (IARI, CAZRI) were deputed to USA for training in specific fields and as an exchange program, Consultants from the USA conducted training programs in India at these institutes. Besides training of key personnel in the various aspects of agrometeorology through this exchange program, sophisticated equipment for field work like spectral radiometers, automatic weather stations, radiation measuring equipment with continuous recording facilities under cropped field conditions, computing facilities (PCs and software) were made available for use at the different agromet units. This has been a good opportunity at the take off stage of the AICRPAM and the effort deserved to be commended. Under the NCMRWF weather based agro advisory scheme also, in-service training programs were jointly conducted at IMD, CRIDA and IARI to train the personnel manning the AAUs. Several scientists from NCMRWF, IMD, and IITM were trained at the advanced laboratories under another UNDP supported project on "Meteorological Applications in Agriculture". In spite of these activities, the country is still short of trained personnel as observed by WMO.

ACHIEVEMENTS IN AGROMETEOROLOGY IN INDIA

All India Crop-weather programme implemented between 1945 and 1970 resulted in establishment of network of Agrometeorological observatories all over the country in the agricultural research farms. Data scrutiny and observatory inspection activities by the national meteorological service have become a routine activity since the scheme came into operation. Crop-weather data with respect to major crops have been systematically collected and archived. An agroclimatic Atlas has been published.

Issue of weather outlook for farmers, agro advisories and their broadcast through radio and dissemination in cooperation with State Departments of Agriculture has been a routine feature towards service to the farming community.

Several crop weather models had been developed from time to time using statistical tools such as regressions, orthogonal polynomials and curvilinear techniques, multiple regressions in respect of major crops for yield prediction purposes at regional level. Along with data collected through crop cutting operations, these have been utilized by the Ministry of Agriculture for yield assessment of major crops every year both on all India and on a regional basis.

An ICAR sponsored Scheme AICRPAM has been in operation since 1983 with 25 centres in the different agroclimatic zones. Its activities include agroclimatic characterization, studies on crop weather relations, climate-pest/disease relations and in-service training programs, and hands-on workshops.

Under AICRPAM several scientists received training in agrometeorology both within the country and abroad. Indo-US program in agrometeorology was successfully implemented which included augmenting of infrastructure (equipment), training and exchange of scientific personnel.

Characterization of climate for agriculture using long time series weather data has been carried out for several locations and regions in the country and is being updated periodically.

Probability analysis, based on time-series climatic data with respect to all major elements of the climate, taking into account requirements of crop planning in agriculture and future risk management has been the mainstay of this activity.

Agroclimatic classification of the country has been carried out from several aspects—climatic water balance, moisture and drought indices, water requirement, potential evapotranspiration, assured rainfall probabilities etc., Agroclimatic zonation, Soil-climatic zonation, agro-ecological zonation maps of the country at regional, state and national level are available today.

Significant contributions have been made towards drought monitoring, development of drought management strategies, and crop contingency plans for aberrant weather, with agrometeorological inputs.

Establishment of a national service in the form of Medium Range Weather Forecast based Agro Advisory Services to Agriculture, with a network of more than 100 centers all over the country, has been a landmark achievement. This coordinated activity of the NCMRWF (DST), IMD, ICAR and SAUs created awareness among the farming community about the benefits and utility of weather-based advisories, resulting in increasing demand for these services.

In tune with concerns about Climatic Change and Global Warming, studies have been initiated in the country towards understanding impact of Climatic Change on Agriculture, UV-B radiation characteristics and gas emission environments. Efforts are underway to estimate all India food-grain production well in advance, through application of ENSO, El Nino indices with monsoon rainfall activity. Results have been encouraging.

Application of recent technology such as remote sensing, satellite cloud imagery, GIS technology, dynamic simulation modeling has become an important activity in the research programmes in agrometeorology.

Creation of a data bank facility in Agrometeorology, supported by the DST in cooperation with ICAR, at CRIDA, Hyderabad with excellent facilities for collection, scrutiny, archival and supply of agrometeorological data was a significant achievement. Recently a Website "Crop-weather outlook" has been launched for providing value added services in agrometeorological information.

Climate of the desert regions, desertification and microclimate of the crops grown in the desert region was studied at the Climatology division of the CAZRI. Vast agroclimatic database has been built up and agroclimatic characterization done. Climatic studies related to reclamation, water and soil conservation, wind and shelterbelts with their microclimate, had been extensively studied and a wealth of information built up.

Application of remote sensing technology to agriculture, where agroclimatic observations, database and analyzed results are extensively utilized for several purposes such as determination of crop cover characteristics, acreage, crop identification, crop-drought assessment etc., has made significant advances in the past three decades.

Human resource development in agricultural meteorology has been an area where several facilities have been created. Short-term in-service training programmes, Summer schools, SERC Schools had been extensively organized from time to time and a firm base has been established in the country for conducting such programs in future. Under UNDP assistance, a few scientists had received training abroad in the study area of "Meteorological Applications in Agriculture".

Establishment of 'Departments of Agrometeorology' at some of the Agricultural Universities in the country for training, research and extension in agrometeorology at post-graduate level, though inadequate, was a significant step that had been taken towards human resource development in the discipline of agrometeorology.

Cooperation and coordination with national and international linkages for the programs in Agrometeorology have been excellent with support and participation of all concerned organizations— ICAR, SAUs, IMD, DST, NCMRWF, ISRO, NRSA, SAC, IITM, IISc, ICRISAT and UNDP. Successful conduct of LASPEX (Land Surface Processes Experiment in the Sabarmati River Basin) program and training of AAU personnel can be cited in this context.

Scientific community of Agrometeorologists in the country, have come together to form an "Association of Agrometeorologists" in 1999. The main objectives are to bring out a journal and organize seminars and symposia to provide opportunities for interaction and mutual exchange of views. A "Journal of Agrometeorology" is being published biannually since 1999 and finds a place in international abstract journals. The Association organized two national Seminars in 2001 and 2003, which received good response.

5.1 SWOT analysis on Development of Agrometeorology in India

Agriculture is vulnerable to climatic fluctuations and it is recognized that it would be beneficial to follow the weather pattern for getting maximum economic benefit from agriculture. However, the economic benefit from the weather based agricultural operations is yet to be assessed.

Strengths:

(a) Initiation of studies as early as 1905 at the Institute of Agriculture at Pusa, accumulation of a climatological data base of more than 100years by IMD, establishment of a special unit of Agrometeorology in 1932 at Meteorological Office, Pune, under the leadership of Dr L.A. Ramdas.

(b) Establishment of agromet observatory network, with systematic collection of crop-weather data on field crops since 1945 to 1970. Network includes 225 agromet observatories, 39 Evapotranspiration stations and 44 soil moisture observation sites.

(c) Initiation of studies on climatic water balance and climatic classification for agriculture under the pioneering lead research by Dr. V.P. Subrahmanyam and associates at Andhra University in 1950s.

(d) Establishment of 'Departments of Agrometeorology' at SAUs. Agricultural meteorology education received a fillip with the able guidance and leadership from Prof. P.D. Mistry for training at PG level.

(e) Starting of All India Coordinated Research Project in Agrometeorology by ICAR, which has 25 centres today operating at SAUs.

(f) Establishment of Agro Advisory Units by the NCMRWF, DST. About 105 units are operating at SAUs for preparation of weather-based agroadvisories twice a week, and dissemination through radio, newspapers, TV and other communication channels. Achievement is that farmers have taken note of the program and became aware of the benefits of such weather-based agro-advisories.

(g) Availability of training facilities through PG programs and in-service training through short-term training courses, summer / winter/ SERC schools, seminars and workshops. This has been an area of a co-operative effort among the DST, NCMRWF, ICAR, IMD, SAUs in the country and a few international organizations (WMO, FAO, UNDP, ICRISAT, Indo-US).

Weaknesses: Sometimes the strengths may be the weaknesses if not suitably mould and developed in the proper perspective. These lie hidden in the strengths.

a) **Poor (inadequate) interaction**: between personnel of State Departments of Agriculture, AAUs and Regional Meteorological Centres of IMD dealing with weather and crop advisories.

b) **Poor data exchange**: Though strong database exists, access to data by researchers is still considered difficult and unsatisfactory.

c) **Human resource availability**: There are islands of excellence but not enough qualified personnel in agrometeorology. Provincial barriers sometimes seem to restrict hiring of personnel from other states.

d) **Human resource utilization**: Due to paucity of trained manpower, personnel belonging to other disciplines are posted to work as agrometeorologists. The problems that are being faced are (i) though some of them take interest in agrometeorology, in several cases, agrometeorology platform is used as stepping stone for career promotion *in their basic discipline* (ii) after being trained in agrometeorology, there is no guarantee that they are retained to work for at least three years in the agromet posts due to transfer or promotion of the incumbent (iii) They do not have background in basic theoretical aspects of meteorology, which is essential for appropriate interpretation of synoptic charts or weather forecasts for application in operational agrometeorology for agriculture.

e) **Non-availability of equipment within the country:** This has been a serious problem and most of the equipment is imported without corresponding service or repair facilities leading to idling of equipment or break in records.

Opportunities: Several opportunities exist. With 127 AAUs to operate, 25 AICRPAMcentres, requirements of the IMD, ICAR, SAC (ISRO) for their institutes, establishment of disaster management programs, risk management and insurance schemes for the agricultural community in the country, and departments of 'Agricultural Meteorology' both existing and those to be started in SAUs, there is sufficient demand for qualified agrometeorologists/ agroclimatologists in the country. Besides these, plant pathology, entomology, agronomy, irrigation scheduling, horticulture, plantation and commercial crops, animal husbandry, veterinary and other research institutions also need agrometeorological support through full time personnel.

Other opportunities visualized are developing consultancy services - in secondary schools and undergraduate education, state government services, traditional universities and NGO organizations. Human Resource Development has to keep pace with these requirements, which is not the case now.

Threats: Some of the threats for development of agrometeorology in India are:

(a) **Quality**: While developing human resources, there should be no compromise with quality of education, forming course curricula, practical work. A low standard can bring deterioration in the quality of agromet advisory services to be provided and thereby losing confidence of the farming community.

(b) **Devotion and punctuality**: Unlike several other services, agrometerological services are to be provided every day without holiday, time bound and need attention all the time. Devotion, punctuality and work in a clock-like mode of functioning, are the essential traits for operational agriculture.

(c) **Basic research:** Presently agrometeorology in India is at development stage and needs to be supported by strong basic research. Lack of support at SAUs to basic research may be a threat, since presently applied agrometeorological research is weighed towards development of empirical, location and time specific technology.

(d) **Lack of Coordination**: Operational agrometeorology implies interaction and coordination of agroclimatologists with scientists and other personnel from other disciplines / organizations both at local and regional level. Inadequate coordination and communication may impair the services to be rendered.

This SWOT analysis is a backdrop for corrective action and planning future measures for improvement of research, extension and HRD activities in agrometeorology and through these services to agriculture, towards maintaining food security and nutrition security.

USER REQUIREMENTS—Response to questionnaires, appraisal

Suitable questionnaires were prepared and circulated to more than 100 institutes, SAUs and individuals in the country dealing with research programs involving the discipline of agricultural meteorology. Response had been very satisfactory and the suggestions and comments received, reflected the nature of reorientation required to be given to the research objectives in agricultural meteorology / climatology with emphasis on more interaction between agroclimatologists and the scientists of other agricultural disciplines. Here the representative samples of responses have been quoted in brief along with the questions, put together and analyzed. Some of the thrust areas which cover topics of both local / regional and national interest have been taken into consideration in preparing the vision document to follow.

Do you find available information on weather elements and rainfall probability information agroclimatic region maps in the present form adequate for your purpose?

"Yes. Adequate". "Not adequate". "Not readily available".
"Rainfall probability analysis has been sparsely used"
"Hourly radiation data and regional maps are not available".
"Information on agroclimatic region maps is lacking".
"Taluk-wise, weekly weather data for cashew growing areas is inadequate"
"The fisheries division, plant pathology, entomology, Natural Resource Division and Animal Science Division at Central Agricultural Research Institute (ICAR), Port Blair Andamans have used weather data on agrometeorology for their research. Information on probabilities is not available"

Comments on the responses:

Response from research institutions reveals that for routine work, access to climatic or weather information on rainfall, temperature, wind, sunshine hours has been considered adequate. However, it may be mentioned that the 'adequacy' refers to only basic data on general weather recorded in the meteorological or agromet observatories and not those measured over crop surfaces or derived relationships. These are still inadequate.

Rainfall probabilities or agroclimatic region maps seem to have seldom been used for advising agricultural operations though such derived information is available for several locations in India.

Reasons for this could be: (i) Except during a few weeks of the monsoon season, in case of the rainfed regions of crop growth, the amount of rainfall estimated to occur is often minimal at probabilities higher than 60-70 percent, indicating inadequacy. (ii) The rainfall probability information is not much related to specific crop growth phase. (iii) How to utilize this information in operational agriculture has not been thought of since most of day-to-day advisories are based on local field experience rather than based on detailed weather analysis related to crop growth in quantitative terms. This situation needs to be corrected.

It is evident that agroclimatic analysis should be related to phenophases of crops. e.g., Information on water requirements of crops can be worked out for each of the growth phases at a location More information presently generated pertains to total water requirement for the whole growth season. Same way, rainfall probability could be worked out in relation to growth phases. Methodology for such analysis is already available. It only needs to be expressed in terms of growth stages for each crop species.

With respect to remarks such as "non-availability of agroclimatic regional maps", all agroclimatic maps published so far cater to "general purposes"; maps, with respect to specific crops is not available. This is a genuine remark needing remedial activity to generate "user targeted agroclimatic maps" for specific purposes and not for general purpose, which has limited use.

Is such information routinely used by your organization for any purpose? If so, the specific topics in which you seek information on interaction of weather elements and crop growth with two or three examples may be cited. If it is considered not of much significance to your area of research it may be stated so.

"Information will help in forecasting significant events of crop growth, health and yield and desired management to overcome the expected biotic and abiotic stresses in crops".

"Useful for forecasting of leaf diseases of banana" (*NRC on Banana ICAR*).

"Information is routinely used to decide whether a given location is suitable for growing sugarcane. The promoters of new sugar factories in the country generally approach us for evaluating the production potential of sugarcane in the proposed operational area of the new sugar factory." (*Sugarcane Breeding Institute, (ICAR), Coimbatore)*

Comments:

As stated above, weather data on mostly, temperature and rainfall are in use at almost every research station. At a few locations (e.g., Central Soil Salinity Research Institute, Karnal), rainfall frequency analysis, rainfall-runoff relations or potential evapotranspiration estimates had been respectively used to work out irrigation demands, or expected surface runoff and consumptive use by crops. However, this is not a routine practice.

Unfortunate part is that several of these relations are derived from field experiments and reported in literature very frequently, but seldom used in practice for routine agricultural operations in the farm advisories which continue to be a blend of local experience and qualitative information available to the concerned scientists/ extension workers from field experiments.

The responses also show that such information is recognized by many, as beneficial and essential. What is the impediment that prevents development of quantitative relationships is a question that merits detailed analysis in this context.

Is information on critical thresholds of weather elements in relation to crop growth in its different phases readily available? If not, what measures would you suggest for gathering this information? It may be mentioned that such information on thresholds enables analyzing data with reference to the thresholds and develop simple prediction models for forecasting significant events in relation to weather. This is also useful to monitor crop growth as affected by environmental conditions.

"Not readily available". "This information is available but not at one location e.g., "State Agricultural Universities and various crop based institutes in India have this information independently".

"This is the most important component. Such information is available in USA Texas State as computer modules and are practiced by farmers for field operations".

Comments:

Response to this question has been unanimous to say that (a) such thresholds are not readily available (b) such thresholds are essential for several purposes (c) such thresholds need to be collected from literature (d) thresholds derived from regression equations vary from time to time and place to place.

It is not that threshold values of weather elements for several events like crop emergence, temperature or humidity optima for pest/ disease development, grain-filling duration etc., for several crop species are not available altogether. Present status is that (a) these values have not been systematically codified or defined (b) there are several gaps e.g., threshold values for each growth phase of a crop species or pest/ disease organism in every phase of life cycle are not available. (c) information is mostly confined to research papers or text books (d) threshold criteria derived from regression equations which are extensively reported are both location and time specific i.e., temperature found significant for an event at a location does not show up as significant in the next season may be, because of year to year weather variations or rainfall distribution which dominates the temperature magnitudes.

Generally, in field crop studies, statistically significant weather elements in each season are identified for development of regressions and reported in literature. These are usually taken as the criteria significant *for each season. Often it has been the case that, why a weather element significant in one season has not shown up its significance in the next season, has perhaps never been investigated. This is a major lacuna in the research perception.*

To remedy this situation, compilation and definition of agrometeorological information for each crop species for every possible event is suggested. This was carried out for banana crop earlier. *Identified gaps have to be filled up through laboratory and field experiments.*

What type of information on weather elements and ready—to—use formats do you feel would be useful in your area of research or planning day-to-day agricultural operations? Would you like these to be prepared by agroclimatologists or in association with your department which could be of practical utility to you? Please indicate in detail.

"Not readily available" is the general response.
Typical requirements mentioned in the responses are: sowing, planting temperature of various crops, phase-wise moisture requirement, disease and pest free weather, drying weather, spraying weather, weather conducive to various agricultural operations.

Comments:

All responses received indicate the usefulness of this type of presentation of information in the form of ready reckoners or nomograms, contingency tables etc., A few sample suggestions from the responses are given here.

"Ready reckoners for irrigation scheduling relating Kc. ET etc. at different growth stages and quantity of water to be applied for different crops in different soil types will be much useful" (*Central Soil Salinity Research Institute, Karnal*):

"Tables on ET at weekly intervals"—(*Sugarcane Breeding Institute, ICAR*)

"Ready to use tables are not available. It will be a big leap forward towards management of field operations" (*CASAM. Pune*).

Ready formats would be useful (*National Research Centre for Spices, Kozhicode*)

Comments:

The responses received reveal the paucity of such nomograms, ready reckoners or contingency tables, checklists etc., which are considered extremely useful. These do not need any specific research, but with the available information these can be devised. This could be seen as a first step towards developing EXPERTS SYSTEM, which can encompass several types of readymade decision supporting solutions for advising agricultural operations using real time crop-weather data.

HRD: Agroclimatologists should be well versed with physiological processes and cultivation practices of crops, pests and diseases, dynamic simulation and programming techniques.

What are the research gaps in the area of climate/ weather and its influence on the specific crop in which you are interested? Please specify the thrust areas that need priority attention on both short and long term basis.

***(As could be expected, response to this has been varied and at times, crop specific. The list below provides a glimpse of the views as expressed by scientists across the country. Most of the responses given here are from non-agrometeorological sections and reflect their requirements and expectations from the agroclimatologists*).**

"All crop-weather relationship studies so far carried out in the country are location specific. A generalized picture is needed"
"Compilation of pest disease organism cycles is necessary".
"Networking of automatic weather stations is desirable".
"Poor agromet observatory network in hilly regions need to be attended to".
"Agro-climatic data requirements pertaining to specific crops are to be identified".
"Accurate weather forecasting is required for advising farmers in different regions with respect to agricultural operations of various crops"
"Weather –crop pest relations to be studied thoroughly and efforts should be made to develop predictive equations for incidence of pest in various crops".
"DSSAT type models are needed".

"Traditional knowledge on crop-weather relations and its relevance in today's context"
"Phenology of plantation crops should be recorded".

"Multi-location validity of dynamic simulation models is suggested"
"Derivation of genetic coefficients at new locations for new varieties is needed"
"Programs for weather forecast, pest and disease forecast need to be incorporated in CERES sorghum model".
"There is no dynamic simulation model for sugarcane".

"Oil content and oil quality of oil seed crops are influenced by climate and needs to be studied". (*Directorate of Oil Seeds Research, ICAR, Hyderabad*)

"Forecasting model for incidence of pest and yield is the research gap for cashew growing regions.(National Research Centre for Cashew, ICAR, Puttur, Karnataka)".

Central Tobacco Research Institute (ICAR) Rajahmundry, AP.
"Studies on adjustment of planting time, water conservation technologies in the erratic rainfall zone of Southern Districts of Andhra Pradesh tobacco growing regions"

"Optima of microclimatic conditions to upkeep the flavour and quality in irrigated FCV tobacco grown in Northern Districts of Andhra Pradesh."

"Onion—Pest (Aphids) forecast models".
"Onion—Yield forecast model need to be developed for deciding the transport, export and marketing strategy"

"Studies on rainfall and yield of black pepper, cardamom, ginger and turmeric."
"Maximum and minimum temperature and their relationships with flowering in above crops to be studied. Relative humidity changes and pest and disease incidence".

"Documentation: Relevant text books, manuals technical notes are not available".

Sugarcane Breeding Research Institute: (ICAR, Coimbatore)**:** "At present, the varieties developed at Coimbatore are taken to different locations and selection is made by studying their performance at each of the locations. This is a cumbersome and time consuming process. Instead, once the performance of the new varieties is known at Coimbatore, it may be possible to extrapolate their performance in any given location of the country by considering the data of various weather elements in the specified location. It is worth to initiate studies on the above aspect".

"Identification of optimum time for planting of sugarcane in different sugarcane growing tracts of the country in relation to weather parameters"

"Yield forecasting in sugarcane based on the prevailing weather conditions is another area where agrometeorological studies would be of immense use".
"Forecasting of pest/ disease attack for sugarcane crop planted on different dates in different agroclimatic regions of the country."
"Mid-term assessment of the growth condition of sugarcane in different sugarcane growing tracts based on weather parameters"

National Research Centre for Banana *(ICAR)*: "The incidence and spread of leaf diseases of banana is directly related to the weather parameters. Study of the parameters with leaf diseases across the country would provide a disease forecasting model for the disease which could facilitate to take up prophylactic measures in advance for the control of the disease".

"Quantification of biological responses in relation to weather is a major gap (Palampur)".

"Surveying and documentation of already existing/ generated data of biological responses for use under AAS activities".

"Generation of functional relationships between biological responses and weather through interdisciplinary approach and be production or protection related (Both in controlled and field conditions)"

Central Institute of Temperate Horticulture, *(ICAR) Mukteswar.*

"Impact of climatic change on temperate fruit crop production".
"Effect of uneven distribution of rainfall and radiation and its relation to soil biological activity".

"Low temperature probability; analysis should be carried out each year to forecast the probable changes in minimum temperature at critical crop growth stages"

Indian Grassland and Fodder Research Institute (ICAR), Jhansi.

Studies on
"Fodder crop – weather interaction"
"Crop growth simulation models in different production systems"
"Crop- weed –weather modeling"

"Impact assessment of climatic change and variability on fodder productivity on a regional basis."

Climatic characterization on individual watershed basis.
Quantification of rainwater availability for water harvesting.

Comments:

The above list is a cross spectral view of the different "user requirements" where studies on impact of climate and day-to-day weather variations need to be investigated many a time involving interaction among the various disciplines. Wide variety of topics for research in crop-weather interactions are reflected in these responses. Some of them suggest specific objectives. Crop specific research needs in relation to climate is also self evident. Problems sometimes seem simple but yet incompletely tackled.

What are your expectations from the agroclimatologists which could supplement activities?

These could be with reference to several areas of crop interaction with weather such as sowing or planting time, vegetative growth, anthesis, flower or fruit setting, maturity, irrigation scheduling, pest/ disease attack drought or water logging etc., In fact, wherever, climate plays a role in influencing specific crop or crops you are interested in may be brought out. Since simulation models are increasingly becoming available, detailed information on each of these aspects would be of immense utility in developing forecasting techniques wherever possible.

(a) in your research area

"Agroclimatologists can provide basic weather data for developing regressions and correlations with crop events"

(Other responses are a repetition of answers to other queries above and not reproduced here).

(b) on-field operations

"He/she can provide weather data for farm operations for sowing, irrigation scheduling, harvesting etc.,"

(Other responses are a repetition of answers to other queries above and not reproduced here).

(c) monitoring crop growth

"Agrometeorologist can help in mid-term assessment of the growth condition of sugarcane in different sugarcane growing tracts based on weather parameters"

"Help of agrometeorologists is required in such areas as water budgeting, scheduling irrigation, weather crises management under erratic rainfall"

"Weekly watching the weather and recording observations on growth and development is highly essential". (National Research Centre for Cashew, (ICAR), Puttur, Karnataka)

(d) use of charts over large areas with disturbed weather conditions

"Useful for making recommendations on midterm corrections for standing crop of sugarcane in different sugarcane growing tracts when there is an aberration in weather conditions"

"Helps in forecasting which aids in going for alternate strategies in case of bad weather conditions".

"Present need is use of weather charts over large areas with disturbed weather conditions, for scheduling irrigation and to control pest disease attack".

(e) interdisciplinary areas of research where both can work together?

"Interdisciplinary team to standardize `Management Practices' for aberrant weather, break in monsoon, flood and drought situations"

"Working with agroclimatologists would benefit us in various fields like disease forecasting, preparation of farm advisory bulletins etc.," (Srinagar, Kashmir).

"Interdisciplinary work involving Agrometeorologists, Plant Physiologists, Plant Pathologists and Agronomists should be strengthened so that results can be passed on to the farmers".

Comments:

Most of the time, Agroclimatologist is seen as a data provider by maintaining an observatory and records of weather and preparing weather summaries or climatological tables. Unfortunately, his/her role is seen to be limited to this. Some have expressed the view that he/she should provide weather forecasts which is done by the India Meteorological Department or NCMRWF. Beyond this his/her involvement in research is not viewed as essential. This is attributable to the fact that mutual appreciation of the subject specialization has not extensively taken place for some reason or the other. Also most of the time, statistical analysis is seen as an end in itself that needs only data input from the Agroclimatologist but not his/her involvement in tackling a research problem in the different disciplines of agriculture.

However, in response to the question on interdisciplinary research, involvement of Agroclimatologist is considered beneficial or even essential. This is a welcome development that needs to be promoted. The Agrometeorologist / Climatologists, on their part should produce such results and present them in a manner that, significance of his results is readily understood and be able to sell his research products to other agricultural scientists. User requirement targeted research is the need.

Do you suggest any syllabus items relevant to your specialization at post-graduate level in agrometeorology to expose these trainees to basic/essential knowledge of your discipline which would equip them to serve specific requirements if any?

Response:

General: Agrometeorology of different crops, agrometeorology of disease, pests, crop growth modeling, simulation modeling by dynamic approach, mitigation of weather hazards by weather modification for crop are of special interest courses to be added at PG level.

Sugarcane:
a) interaction of weather elements on growth and development of sugarcane
b) yield forecasting techniques in sugarcane
c) simulation studies and crop modeling in sugarcane

Temperate fruit crops:
Syllabus may include topic on "Weather conditions and fruit growth development".

Agrometeorology course for agronomists and vice versa is useful.

Grassland and fodder crops research:
Course on water management and basics of crop production at PG level in agrometeorology with reference to grasses and fodder is required.

Comments:

Since several institutions only confine to research and are not "teaching institutions", the response to the above question is limited. This suggests that teaching institutions have a responsibility to suggest specialized courses and syllabi which have a bearing on impact of climate on specific aspects of agronomy, entomology, plant pathology, horticulture, vegetable crops, irrigation scheduling etc., where interaction between two or more disciplines is more essential.

Would you find it useful and necessary to design any short term training program in agrometeorology, agroclimatology for your scientists and vice versa or for both together for better appreciation of the roles they could play in tackling adverse effects of impending weather on the crops of your interest?

"This is very essential for both ways. Some of the best labs in India can prepare modules for this".

"It could promote better understanding of the points of view of the other discipline through follow up discussions"

"A short term training course for the benefit of the scientists and agrometeorologists in crop modeling in sugarcane would be beneficial."

"A short term training program would help in forecasting of diseases and growth models."
"Short term courses are essential to broaden aptitude and research skills".

"Short term training program involving both scientists of different disciplines and agro climatologists would be of great help for both to understand the basic concepts, methodologies and requirement of each other."

"Short term training course to the scientists of agronomy, entomology and pathology in agroclimatology is needed".

"Specially designed short term training programs separately targeted for agronomists, extension specialists of various disciplines (pathology, entomology, horticulture, agricultural engineers etc.,), NGOs, and State Directorates of Agriculture are needed".

Comments*:*

These responses have to be read in conjunction with the responses to the previous question *mentioned above. Courses and short-term training programs should be so devised as to promote better and deeper understanding and appreciation of the specific subject matter perspectives involved in two or more disciplines, of how specialist in one discipline can assist those from the other discipline in furthering research to the benefit of both.*

Any other relevant remarks or suggestions you may like to make may be given here.

(The responses below are general suggestions concerning facilities for networking of weather stations, digitization of satellite imageries, GIS mapping etc.,)

"Agroclimatic maps may be digitized".
"Agroclimatologists can collaborate with Plant Pathologists in developing a module for the forecasting systems".

"Agronomists, horticulturists, entomologists, pathologists, plant physiologists could interact with agroclimatologists to understand each others perspectives and develop strategies for improving crop growth conditions, escape pest / disease problems and their avoidance".

"Continuous weather information through an automatic weather station is needed especially during specific stages of crop growth or at some critical stages when weather for short periods play significant role in disease occurrences."

"Study of Agrometeorology of cashew nut crop in relation to sowing or planting time, vegetative growth, anthesis, flower or fruit setting, maturity, irrigation scheduling, pest/ disease attack, drought or water logging is essential."

Anand Agricultural University, Anand:

"Networking of daily weather data is essential for crop growth simulation models and contingent crop planning".
"GIS facility also helps in understanding zone-wise weather potential, crop yields, duration, zone-wise management of irrigation and fertilizers etc., for the same crop species"
"Facility for digitization of satellite imageries should be developed".
"Data analysis of radiation and thermo-hygrograph are of importance for pest disease weather relationship study".
"Promotion of interdisciplinary teams to resolve agrometeorological problems associated with agricultural operations".
"Development of seasonal weather forecasts is very essential".

Suggestions received on specific crops / topics—(*These are given here to reflect responses received on specific research items of mostly local interest but of utility to others growing same crops in other regions. These include requirements from hilly regions, Andaman and Nicobar islands. Spices and vegetable crop research etc., and provide a glimpse of the problems which they would like to tackle through research in crop-climate relations).*

"Effect of temperature on flower or fruit setting in fruit trees like aonla (aula) and ber".

"Yellow mosaic virus in urad and moong crops during rainy season".
"Incidence and spread of leaf diseases of banana"

"Increase in minimum temperature during maturity of rice markedly reduce the rice grain yield and increase in maximum temperature during flowering stage of wheat significantly reduces the grain yield"

"Appropriate humidity for citrus fruits, mean temperature for cabbage seed production, frost bite on potato, **pigeon pea**, snow bite etc on deciduous fruits and heavy winds on mango fruit setting etc., have direct or indirect effect on yield".

"If clouds of more than 6 *okta* are forecast and rains are also expected, then the harvesting of matured crop is advised to withhold temporarily in case of cereals. The plucking of pods of matured green gram is advised to be hastened. If no rains or soil moisture is limiting the top dressing of urea is advised to be postponed for the time being".

"In horticulture and vegetables one may be interested in rainless periods for sprays, rainy periods for irrigation scheduling, fertilizer application and vegetative propagation and fruit harvesting schedules".

"Modeling for day-to-day decision making in field management of various aspects of agro-horticultural system as related to weather and climate"

"The biotic events of several plantations viz., mango, cashew, sapota, coconut, cocoa, coffee, cardamom, tea, cinchona, walnut, pepper, rubber and oil palm respond to season very much".

Central Institute of Temperate Horticulture (ICAR). Muktheswar:

"Studies on impact of low temperature, its duration, radiation-its intensity, atmospheric temperature on dormancy breakdown, flowering, fruit set, fruit retention, fruit growth and fruit quality of apple, pear, peach, walnut and almond crops needs to be undertaken".

"Effect of foggy weather on disease incidence at different crop growth stages in temperate crops" is required.

"Production of apple crop in Uttaranchal has reduced in the last few years. Possible reason is the change in climate of the apple growing region and needs to be investigated."

"Studies on influence of snowfall, chilling hours, sunshine duration on apple productivity" may be investigated

IARI Vegetable crops Research station, Katrain, Kulu:

"If chilling requirement of temperate vegetables is not met, their seed yield is affected negatively and sometimes with a total failure. Likewise, the day length affects the production in onion etc. High temperature during flowering of french bean, pod setting is affected. Needs to be investigated".

"Possibilities for off-season production of vegetables based on climatic data and yield potential of different vegetable crops still to be worked out"

"Information on snowfall and day length with different aspects of the hilly region is to be investigated".

Effect of weather parameters on concentration levels of minor elements in plant leaves and other organs is a problem for study.

Review of contingency plans after every five years.

Agromet component should be linked to IPM strategies. NCMRWF, IMD, NRSA's efforts to be linked.

Agroclimatic zoning of hilly areas—how much and in which areas is this possible? Network design and sampling techniques for these areas to be devised and standardized.

Operational agromet models to guide farmers on weather-based decisions utilizing short and medium range weather forecasts.

Influence of weather parameters and moonlight on the attraction by light traps and pheromone trap catches.

NRC on Soybean, Indore.

"The effect of varying temperature on reproductive growth of soybean particularly on seed and pod formation"
"The role of temperature and humidity at maturity on seed quality of soybean"
"The interaction of temperature and photoperiod on phenology and growth of soybean crop"
"The interaction of temperature, humidity, and wind velocity on occurrence, and intensity of pests and diseases" is to be established.

Indian Institute of ***Spices Research***: ***ICAR., Calicut, Kerala***:

"Rainfall pattern and yield of spices".
"Rainfall pattern and pest and diseases"
"Light and temperature effects of flowering"
"Light intensity and its relation with yield of spices".

National Research Centre for Cashew *(ICAR),* ***Puttur, Karnataka***:

"Untimely rain during flowering season results in the production of vegetative growth resulting in favourable atmosphere for pest attack".

"Continued spell of low temperatures during flowering and nut set stage resulted in minimum fruit set. On the other hand, rain during beginning of winter season (November to December) resulted in flushing (vegetative growth) and heavy attack of tea mosquito bug pest".

SKUAST-Kashmir, Srinagar "Development and managing climatic data base using modern techniques for an effective recording, retrieval and analysis and for guiding day-to-day agricultural operations."

Central Agricultural Research Institute (ICAR), Port Blair, The Andamans

"There are very few observatories in these islands. As weather varies from island to island hence collection of weather data from many places, assimilation and analysis is required for correct prediction model for crops".

"Standardization and calibration of instruments is required regularly. There is lack of such technical facilities"..

"Lack of technical manpower, training and refresher courses for personnel involved in agrometeorological work needs immediate attention. Due to remoteness, communication and transportation problem prevailing in the Andamans also inhibit attending seminar and conferences at mainland".

"Agrometeorologists having Ph.D. degree will be able to supplement information regarding weather and crop models for forecasting agro techniques whenever required"

"Multi-disciplinary approach is also necessary for conducting the experiments on agrometeorology and future forecast of weather will enhance the mode of operation in the agriculture field/ experiment to be taken up".

"Areas of activities that would be beneficial to the island are: studies on solar radiation, sunshine hours and wind speed and to explore the possibilities of use of renewable energy".

"Basic training on use and maintenance of agrometeorological equipment is necessary for all concerned staff and such facilities should be available throughout the year. Information about center imparting such training also is made available to various institutes of ICAR and other research institutes. A short course on agrometeorology should be included at graduate level in all disciplines of agriculture and allied subjects"

"No significant research work has been done in this field at this Institute due to absence of concerned scientist or agrometeorologist"

The above responses briefly and clearly reveal several user's perception and requirements, which have to be attended to in research programmes in agrometeorology and agroclimatology. These have been kept in view in preparation of the vision paper.

PREVIEW OF FUTURE THRUST AREAS

Agrometeorological research in India can be said to have progressed to a take off stage at present. In several fields of activity, infrastructure has been created to some extent, and a base for services to agriculture had been created. In the coming decades, deficiencies if any, have to be made up and the activities streamlined to make full use of the available resources and strengthen them where required, so as to be able to provide best services tailored to meet user requirements of weather-based agricultural operations. At this juncture, it is considered necessary to discuss in detail, present status vis-à-vis future needs for thrust in agrometeorological activities in the country, with reference to research, teaching and extension and infrastructure development. To start with, a few general problems causing concern in agrometeorological research in the country are discussed.

7.1 Resource Characterization for Production Systems:

General Concerns
***Agrometeorological vs. Agroclimatological Research*:**

The terms "Agrometeorology" (or agricultural meteorology) dealing with the physical processes in the air-plant-soil continuum and "Agroclimatology" (or Agricultural climatology) that deals with the statistical summaries of observations, on the crops / farm animals and the surrounding air layers are very often synonymously used.

Literature survey in the country shows that more than eighty percent of published research is devoted to study of agroclimatology. Rainfall probability analysis, climatic water balance, regressions (partial, multiple, step wise, curvilinear or orthogonal polynomial expressions etc.,) between weather elements - mostly rainfall, maximum / minimum temperature, humidity, sunshine hours, pan evaporation, and radiation parameters to some extent, predominating over studies on energy balance, microclimatic processes (transport of heat, momentum, water vapour or wind etc.,). Partly this situation can be explained due to easy access to abundant long-term series of daily rainfall data, and to some extent on availability of daily weather data on other associated surface observations (temperature, humidity), made from the Stevenson screen at the meteorological and agromet observatories in the country.

Lack of development of portable, battery operated instrumentation for studies on radiation, microclimatic processes, photosynthesis or aerodynamic or crop resistances *in situ* in cropped fields would have contributed to a large extent to the above situation. Even today we have not made much headway in this direction and still depend on imports from abroad for these equipment and had not taken steps to start their indigenous production. Though some equipment were fabricated in the early 1940s and 50s in the agromet division of IMD, for some reason or the other, these were not available in numbers either from the department or on commercial basis. Research on "Agroclimatological" aspects thus seems to have become more popular. It continues to be so even to this day.

In areas with high weather variability like our country, it is known that agroclimatological summaries even if based on more than 60 to 70 year data series, often fail to represent or reflect the situations under "current weather" in any year. It is well known that climatic statistics of rainfall and its distribution (which is the predominant element determining crop growth and yield through contribution to soil moisture resources), do not exhibit any periodicity. Even the derived indices developed for identification of drought or flood events do not provide a realistic indication of their likely recurrence in a current season. Thus statistical crop-weather or pest/disease-weather relations in spite of being found to be statistically significant, are not only 'location specific', but also 'time specific' which is not generally realized. At several locations, the probability levels of occurrence of assured rainfall amounts usable for field operations in agriculture are very low (rarely exceeding 30% or so). Hence the need for intensifying research on an alternative and supplementing approach—using the agrometeorological approach which can at times, provide universal expressions for the short-period crop-weather responses with wider applicability, irrespective of location or current weather in any year, and also not requiring long time data series.

The urgent need is, while continuing with agroclimatological (statistical analysis) approach, which enables us to identify the significant causal parameters in crop-weather relations, efforts have to be increased to inculcate in the scientists both by way of attitude and training, the need to strengthen studies on "agrometeorological" aspects of crop-weather relations. Study material at postgraduate level consists of syllabi on agrometeorological processes but this branch of study, is seldom pursued by the candidates after post-graduation. The situation needs to be remedied.

***Urge for innovation in research*:**

As in any other field of research, more so, research work in agricultural meteorology or agricultural climatology in the country is done on the 'beaten track' considered to be a safe ground. There is tremendous scope for innovative research. Most scientific personnel at the State Agricultural Universities being burdened with undergraduate and post graduate teaching, examinations, answer script evaluations, seminar workshops, report writing and other administrative work, low numerical strength, and lack of library facilities close by, perhaps find very little spare time for giving thought to newer approaches to experimentation, analysis and research. As such, there are several known unsolved problems in the subject-discipline of agricultural meteorology, which need urgent solution, with an interdisciplinary approach, in several cases.

But we are constrained to note that urge for innovation has not been a motive. Major agricultural research institutions at national level with excellent library facilities should ponder over this and take remedial action for encouraging lead research. Paucity of trained personnel due to administrative and recruitment constraints also adds to this. But, our national economy being dictated by monsoon activity every year, agrometeorology and agroclimatology units in the research institutions need more than the presently available support, recognizing them as priority areas.

Providing training abroad to selective number of scientists alone does not bring about motivation for innovative research. It should come from within the country by encouraging and rewarding scientific personnel who show such motivation and also strengthening the infrastructure both by way of equipment and human resources.

Agroclimatic Characterization –New approaches

Age-old practices hardly die. We still confine ourselves to computing "climatic summaries" and, introducing a single factor of potential evapotranspiration or its fractions, or ratios depicting aridity or moisture adequacy index, one feels satisfied that he is doing "agroclimatic" analysis. It is mostly a climatic analysis.

"Climatic summaries" which have a different purpose, by themselves, should not be described or utilized as "agroclimatic summaries". It is well known that every crop species or even every cultivar has its own pheno-phase development, length of growing duration and different water requirements at different growth phases, in each season. This is the crux of the problem. While this factor is recognized in principle by agroclimatologists, when coming down to brass tacks of analyzing weather elements in relation to crop growth, in general (with very few exceptions), no crop characteristic is introduced to define the threshold value of the weather parameter in relation to the crop for analysis. The one understandable reason that can be guessed is the dilemma faced in deviating from fixed calendar dates for analysis; and secondly, certain apprehensions about introducing heterogeneity inherent in year-to-year variations in pheno-phases, into the analysis. Three or four questions that need an answer to overcome this problem are:

(1) Basic weather data being same in a cropping season, for the different crop species grown within the same season, can we distinguish its effect from crop to crop as being separate?

(2) For the same cultivar or crop species, pheno-phase shows year-to-year variation. Would it be wise to fix pheno-phase duration for say a crop species once-for-all (say an average value) at a location for purposes of analysis?

(3) If such an analysis is performed, over a large state, within the same year, different parts of a big state would exhibit differences in time of occurrence or duration of pheno-phases. How can this be realized and reflected in agroclimatic analysis?

(4) When it is already known that year-to-year variation in pheno-phase duration is imminent, would it be prudent to adopt this variable for agroclimatic analysis?

We can find answers for these genuine apprehensions. Rather, one cannot escape but has to necessarily find a viable solution for the above, for bringing any characteristic variation of crop factor into the analysis, which can be more rational than directly using "climatic analysis". Many a time this can be achieved by rearranging available weekly climatic summaries at every location, where the agroclimatic analysis is desired. The following suggestions are made with respect to each of the above queries, which can be open for discussion at an appropriate forum or fora.

1. Yes. (a) Date of sowing and by implication, date of start of analysis could be different for each crop species; it need not be the same for all crop species (b) 'early', 'normal' 'delayed' sowings within a growth season, are already recognized by agronomists and the corresponding average dates can be taken for start of agroclimatic analysis with respect to a cultivar raised within the crop growth season. (c) Even if sowing date is taken to be the same for all crop species in a season at a location, pheno-phase durations differ from species to species. So analysis would be distinct for each case and easily distinguishable.

2. It is very true that year-to-year pheno-phase durations for the same species vary to some extent. However, from extensive field experiments, agronomists, plant physiologists and plant breeders, evolved information on average number of days or weeks from date of sowing for expected duration of phenological phases for different species for different locations. In a agroclimatic analysis which deals with an average situation, these "average virtual fixed weeks" as we may name them, for each location can be utilized as a base for analysis since for the past seasons, where actual dates on phenological events were not available, these dates/standard weeks can be substituted.

3. As mentioned under item 2 above, for each location, these average weeks have to be collected and analysis carried out at each location and then a spatial distribution map made to identify

differences within an agroclimatic region. Such a database would be handy for advising agricultural operations in seasons of aberrant weather.

4. Yes, This suggested approach is more rational than using a fixed calendar date for analysis for all crop species. As mentioned above, climatic summaries can be modified into agroclimatic summaries by rearrangement of weeks by appropriate assignment of standard meteorological weeks to the phenological events of crop species under consideration. A few published research papers are available in the journals and these can be consulted.

***Calendar months vs. monsoon onset and withdrawal dates for agroclimatic characterization*:**

Another variation in analysis that is needed is: For general climatological summaries, IMD has recognized four seasons in a year based on fixed calendar months for the entire country, for convenience. While this serves the general purpose, for crop specific or local purposes, these statistics are inadequate. It is very easy to visualize this, since the onset and duration of monsoon has a latitudinal / geographical variation, the duration decreasing from south to the north in the country, by more than 30 days. It is also known that 'normal onset and withdrawal dates' are different for different regions of the country. Even the 'normal dates of onset or withdrawal' are known to have a range of nearly plus or minus two-week period. Working out 'normal' values for June to September for all stations in the country for the *kharif* season, would not obviously serve the desired purpose of agricultural operations.

Logically, it should follow that for use in agricultural operations, data analysis for monsoon (*kharif* season) should correspond to the dates of onset and withdrawal at each station depending on its location. These can be identified each year. Spatial continuity can be kept by working out the analysis for each station and then depicting them in a map form for locations within a contiguous geographic or agroclimatic region. Of course, this variation in the analytical procedure for climatic characterization which would be more realistic, has to be followed, not necessarily by the national meteorological service, but can be undertaken by any one interested-in, or dealing-with agricultural operations, like the SAUs.

Unfortunately, this procedural modification has not been brought about into our system of weather analysis for agriculture. It is high time that this modification is introduced while contemplating agroclimatic / climatic characterization for agricultural purposes.

***Single station and regional scale of analysis*:**

Every single individual farmer anticipates the best yield for his efforts. Thus, weather-based agroadvisories are expected to suit his requirements. Scale of agromet or agroclimatic analysis assumes significance in this background. Analysis starts with a single station and this directly can be used to formulate weather-based agroadvisories for that location and a meso-scale region around but not for the whole agroclimatic region.

On the other hand, when a weather system like cyclone, heat or cold wave passes over a region, or when monsoon rainfall activity is widespread, it often becomes necessary to have access to regional scale analysis. Also such regional boundaries vary every year. Characterization on a regional scale assumes significance and identification of flood / drought zones, heat / cold wave affected zones, pest-disease affected zones would facilitate regional scale operations by the state. So, agromet characterization both at single station level and regional scale would be of utility.

Building up of data on crop phenological events for agroclimatic analysis:

For phenology based agroclimatic analysis, immediate attention has to be paid for data collection on dates of phenological events for early, normal and late sowing times at a location for each of the major crop species. In the 'All India Coordinated Research Projects' for major crops, such information is reported only for date of sowing, anthesis and maturity. This is insufficient for agroclimatic analysis such as moisture availability or drought probability analysis, since the probabilities vary depending on the growth phase requirements, which are separate for each crop species and for early, normal and late sown crops. The type of weather warning to be issued for expected adverse effects on crops depends on the growth stage of the crop.

In addition to the above, in every major experiment of a research station and in the farmer's fields regularly visited by agricultural experts and extension workers, it should be made a routine to record data on phenological events every year. This will add to the wealth of data, which, if not recorded every year would be lost forever. Such data acquisition helps in mapping distribution of phenological events, which would aid both research and agricultural operations at regional and national levels.

Agrometeorological Information for Crops

Weather threshold values for events in crop growth and development:

Agrometeorological information in respect of major crops has been reported in several research papers and continues to be reported and updated. The information contained therein for several crops remains to be brought together and compiled at one place, as far as climate is concerned viz., effects of temperature and sunshine thresholds etc., in relation to crop growth and development (biomass accumulation, root growth, anthesis, grain filling rates etc.,) pest / disease development, utilization of radiation and soil water, expansion of various plant organs in relation to weather and others. Such information both from laboratory and field experiments needs compilation. (An example of compilation of such information can be found in the WMO Technical Note TD-237, CAgM report 29, on "Agrometeorological information for the banana crop". Published in 1988)

Definition of Agrometeorological Information for Crops:

The next step after compilation of agrometeorological information is to identify and define the threshold values of weather elements in relation to crop events. This is a high priority area with immediate application potential. Such definitions form the basis as reference points for all further analysis aimed at development of weather-based agroadvisories to distinguish between favourable and unfavourable weather situations. Threshold values for giving early warning for selected hazardous events were provided in the crop-weather calendars in the early 1960s, but for illustration, comprehensive definitions of thresholds can be seen in the WMO Technical note TD-757, CAgM report 70. ("Definition of agrometeorological information required for field and bush crops" published by WMO in 1996).

Characterization of Climate for Agriculture:

Climatic characterization of every raingauge site in a state is essential. Rainfall statistics, rainfall probability, water balance statistics at weekly intervals, forward and backward accumulations for threshold rainfall amounts etc., can be worked out. These can be depicted as isoline maps. In addition, rainfall, evaporation and runoff can be depicted on volume basis instead of depth over a regional scale using the same base data. Several users need the data in different formats and aerial extents, such as a watershed, drainage basin, *mandal*, taluk, district, or agroclimatic regions delineated earlier. Once a map showing the distribution of any parameter is prepared for every location on the rain-gauge network basis, irrespective of the administrative boundaries, it would be easy to transform this map into any desired form for any desired area, by appropriate superposition of the desired administrative unit either manually or using GIS mapping techniques.

Such maps would be useful to superpose any other parameter such as air temperature, evaporation, bright sunshine hours, cropping pattern, crop pheno-phase maps, animal husbandry, poultry population distribution, crop or milk yield, irrigation requirements, water requirements etc., for any specific targeted objective of study.

Agroclimatic characterization for crop production systems:

In the country, crop based production systems are recognized. Rice based, Rice-wheat, Oilseed based, pulse based, cotton based production systems are a few examples. For ready reference it would be of practical utility if the agroclimatic characterization is done with respect to such production systems. As mentioned earlier, once base maps are prepared for every raingauge location, GIS technology can be used to delineate the areas adopting such production systems. No major new analysis would be necessary. Benefits of such analysis as a ready reference would be evident after the characterization is done as this would replace the general-purpose climatic characterization and bears a system-specificity.

Interpretation of Research Experimental Farm Results in Relation to Natural Field Conditions with Varied Land Use:

It is well known in agricultural circles that there is large gap between yields recorded at experimental research stations (we may consider this as being recorded under controlled conditions and a homogeneous situation) and those observed on the farmers' field with diverse situations indicating heterogeneity. There may be only one research station, which is to be considered as representative of several agricultural farms that are spread over an entire district (heterogeneity in land use); or the research station is taken to be representative of one whole agroclimatic zone (considered climatologically homogeneous). The observed differences in yield between several locations are usually explained away due to vast differences in farm management practices and levels of management, input availability and its non-optimum utilization and for various other reasons. Added to this there are reasons attributable to differing weather situations like spatial variability in rainfall distribution (heterogeneity).

From weather point of view, apart from the farm management levels, there are reasons for vast differences between results of experimental research station and the district yields. Individual station rainfall or crop yields are not accounted for, but more often than not, averaged over. Within an agroclimatic region, year-to-year variations in rainfall distribution (both in amount and durations), tracks of passage of adverse weather systems (depressions, low pressures, heat or cold waves etc.,) could be the major cause for observed yield variations or cultivar performance. This is a factor, which introduces *unitended heterogeneity in sampling* for yield assessment from weather system point of view, even where all the sampling sites are located within the same region, which is considered agroclimatically homogenous. Unless the areas of these weather systems are demarcated for the agroclimatic zone *every year for every weather event*, it would be unrealistic to group all locations even within the same agroclimatic zone, for average yield assessment. Areas affected by adverse weather or even favourable weather, require to be *delineated each year based on synoptic maps* before averaging the crop yields for appraisal or for selecting locations for averaging data.

Quantification of Rainwater Availability for Water Harvesting

Whenever severe or disastrous drought occurrence takes place, one is reminded of harvesting of rainwater. However, this need not be an activity only for drought years, but should be a year-round process whenever there is possibility of rainfall occurrence and its conservation. Immediate application of this type of information is, in the determination of design specifications of structures for water harvesting and their location. Such harvested water during rainy periods could prove to be a viable source for supplementary irrigation in the periods of drought occurrence. This analysis can have several dimensions:

(i) *Harvestable water on a climatic basis*:

Information preferably on a weekly time period, on probability of amount of water that could be harvested can be worked out on a climatic basis using normal weather data, and validated through field experiments. In the context of the Indian subcontinent dominated by monsoon activity, after computation of harvestable water values for the individual years, it should preferably be grouped for (a) high, normal, low seasonal rainfall years separately, and also (b) for early, normal and late onset of monsoons, and (c) for early and late withdrawal of monsoon years of the past. Such maps would have practical application in agricultural operations.

(ii) *In-season determination of harvestable water from cropped areas*

This is best done every week within the cropping season by monitoring real time situation with regard to occurrence of rainfall, nature of crop water requirement or evapotranspiration that had occurred, antecedent soil moisture which determines the runoff depending on the soil type. In this age of dynamic simulation modeling, it is desirable that efforts are made to develop simulation models for these computations. This can lead to development of some sort of risk-avoidance mechanism for providing irrigation during rainless crop-growth periods.

Determination of Potential yields of crops in the rainfed regions based on weather and agroclimatic characterization

'Potential crop yield' usually conveys the meaning that it would be the highest possible yield attainable with optimum management practices under non-stress conditions whether it is moisture, pest-disease or nutrient stress. However, since stress is a frequently recurring phenomenon in the country, we can introduce the concept of *different potential yield levels* in relation to 'wet', 'normal', and 'drought' *kharif* seasons in relation to aridity or moisture availability indices for the different agroclimatic regions in the Dryland areas of the country. As a first step, potential yields for the three different types of seasons can be compiled from the results of agronomic experiments at Dryland research stations throughout the country. These can be further refined through application of water balance or crop-weather models

In Dryland agriculture, crop yield levels obtained in the different years can be described or categorized as 'high', 'average or normal' and 'low', corresponding to seasons of 'above-normal' (wet), 'normal' and 'below-normal' (drought) rainfall years. Farmers' expectation at the sowing time understandably would be to receive at least average yields almost every year. Instead, midway in the season they should be prepared to expect difference in potential yields in relation to differences in rainfall activity. Though this is qualitatively known, the above analysis would give a quantitative base for yield estimation. In the Dryland regions, in any year, it would be possible to estimate the final yield level by the amount of rainfall and its distribution received half way through the crop growth by monitoring water balance (or aridity and moisture availability indices) at weekly intervals in the different soil layers by measurement or estimation from models run within the season.

Field layout and Data-Collection in Crop-Weather Experiments— need for standardization

Currently the main source of relevant and concurrent crop-weather data appear to be the sowing date trials carried out under the All India Coordinated, / National, / Crop improvement projects with the ICAR and by the Agromet divisions of SAUs. There does not appear to be any standardized methodology followed for layout of fields, collection of phenological data, which was meticulously recorded in the Crop-Weather scheme that was in operation till about the year 1970. Most of the published papers on crop-weather relation studies often relate to single stations and one gets the impression that either too much is being read into too little data or significant pointers to weather relations of a crop go unmentioned. In view of this, in the field experiments, there is an urgent need to standardize field lay out, sampling of biological material and data collection, scrutiny and archival procedures for individual crop species.

Forms of Presentation and Nature of Data Needed

Agrometeorologists should ensure that the information is relevant, accessible and presented with clarity. "Standard week" is the accepted time-unit for compilation of agromet data in India and a large volume of data is readily available on this basis. Preparation and presentation of data may continue to be on the standard week basis. For operational purposes, the format may be such that current values of weather elements are shown against the background of corresponding "normal" values based on long-term averages.

'Normal' values of weather elements as prescribed by WMO have to be worked out and differentiated from 'average' values. For operational monitoring of performance of crops in relation to the realized weather in a current season, it is necessary to know the normal values of weather elements for the reason that one cannot decide if a crop situation is abnormal in an year, without a reference to a 'normal' weather. While agroclimatic characterization is done, this has to be kept in view.

Both on a real-time (current weather data) and on a climatological basis (long term normal values) for operational purposes, data presentation in map form would be preferable to individually depict, spatial spread and intensity of incidence of (a) tracks and aerial extent of passage of depressions, cyclones (b) incidence and spread of drought (c) heat and cold waves (d) hazardous weather phenomena like frosts, heavy rains, floods, high winds etc (e) Incidence / outbreak of a crop pest or disease.

In case of agricultural drought, the task would be more extensive. For each species, or even individual crop phases that have predominant significance in yield reduction due to moisture stress, drought intensity may have to be depicted more or less on a daily basis or at least once in three days in map format. These have immense utility for several purposes in preparation of weather based agro advisories throughout the cropping season. With GIS technology in use, this should not pose a problem once the appropriate data are acquired both from field and laboratory experiments.

On a climatological basis, agroclimatic atlases showing distribution of normal values of weather elements had been prepared for certain states. However, these are yet to be revised to depict such distribution in relation to crop growth phases for major crop species grown in the region which will be a true agroclimatic atlas. This is a priority area that needs attention. The lacuna relating to Crop-Climate 'Normals' needs to be made good as early as possible.

Agroclimatic Zonation of India

Agroclimatic and Agro-weather zone maps:

Studies on Climatic classification in India were initiated at Andhra University in the 1950's. With the publication of a rational climatic classification for India these studies were pursued enthusiastically with several variations and subsequently several agroclimatic classifications (including factors such as soil characteristics, moisture adequacy or deficiency indices, assured rainfall probabilities, fractions of potential evapotranspiration) appeared and agroclimatic zone maps published. Agroecological zones were carved out of the agroclimatic zones at national, regional and sub-regional levels to delineate and identify site-suitability zones for cropping. Thus several versions of agroclimatic classification are available for the country. These do not seem to have been put to much use in practice for crop planning, the purpose for which they are made. Information on these types of zonation now available is considered sufficient. This exercise needs to be approached from a new angle.

Agroclimatic zonation can be done several ways. Zonation with weather data or derived parameters, along with crop parameters in a current season, serves a useful purpose. It is possible to map out flowering time isolines for a crop like paddy all over the country in the *kharif* season or anthesis dates of wheat for wheat growing areas in the *rabi* season; flowering pattern in mango crop over the country superposed by day length or thermal time accumulation; dates of incidence of pest / disease organism across the country for a specific pest or disease pathogen, expected harvest days for a crop using dynamic simulation models etc. The list would be endless since for each crop species such information can be included in a **agro-weather map** *with real time data* in a current crop season and as an **agroclimatic map** *with historical data*.

With GIS facilities on hand, once data are acquired from crop observation field sites, in a current season, such agro-weather zones as they may be called, can be prepared. It is obvious that these will have several uses in planning agricultural operations in a current season. A few agroclimatic average maps on flowering dates of mango, wheat and cashew crops had been published in the country, but present necessity is for "in-season" information along with the past.

Information on Unsuitability of Crops in Agroclimatic Zonation Maps

Usually, emphasis is laid on suggesting suitability of a crop species in a particular soil or agroclimatic zone. However, it is felt that it would be more useful to include statements about unsuitability of the sites for specified major crops. This need arises since, soon after electric power is made available at a new site, even if the site is situated in a well-known drought core area, farmers get tempted and resort to raising irrigated paddy crop in place of traditional drought tolerant crops like millets, or sorghum which ultimately lead to over-exploitation of ground water source and electric power. Delineation of areas unsuitable to major crops in the Agroclimatic or Agroecological maps may prove to be a better guideline to farmers which makes one think twice before planting a crop unsuitable to any location.

Agroclimatic Zoning of Hilly Areas

Agrometeorological observatory network in the plains of the country is sufficiently adequate for drawing up agroclimatological summaries or zonation. However, network needs of the hilly and island regions (The Andamans and Nicobar) warrant a review. As such, hilly regions (Himachal Pradesh, Uttaranchal, Assam, and North eastern hill regions and others) pose a problem for networking or agroclimatic zonation since, differences in aspect and slope of mountainous spots play an important role in receipt of solar radiation, evaporation rates, rainfall amount and distribution.

From agrometeorological, crop growth and pest/disease development points of view, duration of daylight hours, dew, snowfall, fog occurrence and their duration, play an important role in these areas. Distribution of rainfall, radiation, duration of bright sunshine, wind direction and speed, in these regions can be highly variant and **spot specific** depending on the location on the hilly region, where the observer is placed. Significant variability in hourly values due to upslope and drainage winds are also common.

Agriculture is practiced in these regions, in the valleys and some times in pocket areas on the slopes. Agroclimatic information for these regions is essential because the hills provide alternate climatic conditions for breeding of new crop varieties, when the plain regions have severe summer or winter conditions. Hilly areas provide congenial climate for breeding or over-wintering for host pathogens and insect organisms, and these areas are also suppliers of vegetables, horticulture and live stock products to the neighboring plains.

This is a priority area and several points that need consideration concerning these regions are:

Would it be of any utility to take the whole hilly region to delineate agroclimatic regions with sparse data or would it be prudent to characterize local climate individually depending on the spread and intensity of crops and animal husbandry?

Is the present agromet observatory network and equipment optimum and sufficient? In what ways can this be improved depending on the projected requirements?

Would it be more meaningful to confine climatic characterization to hospitable and comfort pockets or zones for both crops / animal husbandry?

How far can installation of automatic recording equipment (weather stations) and at what locations would it be feasible to do so to obtain the needed information? Both access, security, availability of instrument service centers— probably within 100 km from the instrument site, may be typical of the logistics involved.

What is the type of specialized crop-weather data set needed if any, at each location apart from the routine measurements on rainfall / snow, temperature, dew, wind and sunshine?

Climatic characterization of hilly regions is a tricky but important problem. A few meteorological and agromet observatories are presently functioning in these regions but in the light of above queries raised, these need a review from the point of view of operational agriculture and development of weather based agroadvisories for the hilly regions. This is a priority area that needs attention. *A small working group may have to go into this issue for making specific report on the status and future needs of the hilly areas. This group can also examine the network and facilities needed for island areas as well.*

7.2 Research and Development

Functional Relationships for Crop-Weather Interactions:

Generation of response functions between production and protection related biological responses and weather through interdisciplinary approach

We are in the age of applying dynamic simulation techniques in several areas. We have abundance of qualitative information developed from field and laboratory experiments. However, even where such information is acquired by local expertise, it remains with the scientist or extension workers concerned or passed on from one to the other orally, or reminisced long after and is yet to be compiled in a written format for each agroclimatic region with respect to crop response to varying agricultural practices. Otherwise it can be considered as valuable information lost forever.

Coming to the field of agrometeorology, the immediate need is for determining the rates of agrometeorological processes, (to be distinguished from general qualitative agronomic information) for agroclimatic analysis, simulation modeling and other purposes. We need information on likely quantitative changes that would take place in growth rates of various plant components and rates of utilization of water, radiant energy, carbon dioxide, partitioning coefficients affected by weather and soil moisture stress, rates of development of pest / disease populations etc., in response to daily weather variations. Determination of quantitative variations in product output is an important factor. This means, information on response to imposition of short -period weather-induced stress of various types (moisture, heat, cold, pest/ disease etc.) on crop performance. Information on rates of processes is very meager and wherever it is presently available, as mentioned above, it is qualitative and not usable in simulation modeling exercise, or usable with real time weather data with any reasonable success.

Reasons for this are two fold:

(i) Conventionally, such quantitative data generation is to be done through experimentation in growth chambers or since the late 1960s, through using phytotron facilities. Both are prohibitively costly and in our country, need import even to this date. Incubators used in several institutions do not serve this purpose as scope of introducing control facilities for environmental parameters to represent field situations, are very limited in such a set up.

(ii) We do not as yet know how to unfailingly transform results from such controlled experiments with growth chambers, even where they are available, to field situations which experience diurnal weather variations. The result is that, we are not in a position to reproduce and simulate field-observed rates of processes induced by short period weather variations (be they diurnal, 3,5 or 7 continuous spell days' effects on crop growth rate processes) under natural field situations.

How can this situation be remedied is the next question. It is clear that due to logistic problems, for the next two decades, our capacity to build / provide and maintain phytotron facilities at more than 4 to 5 locations (it is a guess whether even this is attainable unless dedicated financial, personnel and instrument fabrication efforts are made), is obviously limited. Even providing walk-in growth chambers to fit large size green plant material, is a difficult task and may be a wasted effort because of limited output with respect to field observed results.

Alternative is:

(i) To provide continuous recording facilities from field plots using portable instruments and data loggers, which can record events round the clock. While this can be done in case of weather and physiological parameters, changes in some of the plant parameters are not expressed in measurable quantities, say, for less than weekly intervals. Keeping flexibility in frequency of observation is important.

(ii) To utilize dates of sowing experiments for such short period measurements *in situ* which may necessitate ready availability of multiple sets of sensors with automatic recording facilities. Experience shows that a three-season study, with three to four dates of sowing with three varieties of a crop species with distinguishable morphological or growth characteristics could provide response patterns within a short time by plant

Measurement of rates of physiological parameters (e.g., photosynthetic rates, canopy, leaf, aerodynamic resistances, partitioning coefficients between plant organs) in relation to short period weather variations, and stress indicators (thermal time, evapotranspiration, soil moisture depletion rates etc.,) can be obtained through field experiments and relations established through simulation programs by iterative process within a three to four year period which may correspond to pre-release cultivar trials.

This task involves careful design and standardization of experimentation, observation procedures, data sampling techniques, maintenance of instrumentation and needs devoted attention of small groups of researchers in inter-disciplinary project mode. This is achievable if concerted and cooperative efforts are made by all concerned.

One may ask why these types of rate process determinations cannot form part of post-graduate programs in an agricultural university or national institutes. It could be so, but at teaching institutes, projects with one or two very limited but important specific objectives are not attractive to prospective candidates for post-graduate programs partly due to apprehension that, the whole experiment may fail due to natural calamities or unforeseen field situations where one may have to end up without fulfilling the objective within the time limit set for post-graduate work. Such experimentation should be encouraged (in project mode) as 'institute programs' at the major research institutes, with participation of permanent scientific personnel along with post-graduate candidates, which is very feasible. These can be considered as very important 'part/component research programs', which contribute significantly to a 'whole'. The onus is on the research managers who can impress on the scientific community the rewards of such *"limited-area but targeted research programs"* and ensure provision of all research facilities that are accorded to bigger projects / programs.

Pre-release agronomic trials and development of crop-weather relations:

Plant breeders, agronomists, entomologists and plant pathologists conduct pre-release trials simultaneously for a few seasons before the final release of the new crop cultivars. Demonstration experiments are also laid out. Though their analysis includes statistical tests on cultivar-environment interactions for their significance, these do not lead to establishment of any specific crop-weather response functions.

Crop-weather relations by agrometeorologists are usually attempted long after release of such cultivars to the farmers and sometimes, after lapse of five to ten years. The choice of cultivars by agrometeorologists many a time is apparently *ad hoc* depending on a research problem taken for study and availability of seed material. Thus the findings may become outdated and lose their significance.

Establishment of crop-weather response functions should invariably be synchronized with the pre-release trial period of new cultivars. It affords an opportunity to agrometeorologists to interact with other scientists who are concerned about weather effects. This way, these studies can keep pace with the findings of sister disciplines and all the aspects can be integrated for better interpretation, before the final release of cultivars. Emphasis by agrometeorologists during the pre-release trials or demonstration experiments should be on deriving crop-weather response functions with respect to short-period weather-induced effects on crop growth and yield.

Micrometeorology: Microclimate Modification

Crop microclimate:

The crop as it grows in height and spread, develops its own microclimate as influenced by macro weather systems. Micrometeorology deals with environmental conditions within and around the canopy. It is a result of crop-environment interactions and influenced by meso- and macro scale weather on occasions. Momentum, heat, moisture, CO_2 transfer processes, pest/ disease incidence and growth, effective dissemination of pesticide sprays are all part of the microclimate system. Energy balance of glass/polythene housing, animal shelters is another area for microclimate study.

Microclimate modification:

Microclimate can be modified to partly offset adverse effects of weather aberrations through application of mulch, growing shelter belts and wind breaks, irrigating the field where feasible, creating small fires in case of frost and such other means. In every such activity the microclimate is modified and it is essential to know microclimate characteristics before and after modification whether it is crops or livestock. Impact of air pollution on plants is another area related to microclimate.

Microclimatic processes:

Microclimate processes are the least studied aspect in the country. Time schedule for chemical sprays, dissemination of the chemicals and their effectiveness in relation to weather are the other related aspects. From operational point of view, since it is not feasible to obtain microclimate measurements from every cropped field, it would be useful to develop macro-microclimate relations at different locations for interpreting microclimate in terms of macroclimate measurements in the open. This should be a routine exercise in research experimental plots at agromet research stations. *It may involve generation of large database even at one single location on microclimate in cropped fields* At agricultural research stations, establishment of micrometeorological towers would be a multi-purpose utility both for research and agricultural operations. This is another priority area for the coming decades.

Hourly Data:

Recent advances in Agrometeorology have brought to the fore the need for hourly values of temperature, relative humidity, solar radiation, rainfall, wind speed and direction for a basic, weather-based understanding respectively of (a) Phenological development of crops (b) conditions favoring incidence and multiplication of crop diseases (c) simulation modeling

(d) duration of heat/ cold stress (e) hourly distribution of photosynthetically active radiation (PAR), net radiation etc. Need for hourly data from hilly regions has been mentioned earlier.

Hourly data are also needed as data input for dynamic simulation modeling, micrometeorology of crops, short period weather influence on crops, sequential occurrence of weather elements at critical threshold levels etc. Some of these requirements are presently being met through harmonic analysis of maximum and minimum temperature or through interpolation of monthly data which is not very satisfactory. For several years, IMD has been maintaining self-recording instruments such as the thermograph, hygrograph or thermo-hygrograph for recording temperature and humidity parameters at some of the meteorological observatories. Data have been published only for a few years though the charts are analyzed regularly and data sheets are prepared after scrutiny, and preserved.

Since the 1990s some automatic weather stations that provide hourly data have been installed in agricultural research institutes and universities. These have not been installed on any network basis but presently cater to the needs of individual research projects. The data do not seem to be archived on any systematic basis.

Crop-Weather Models Using Dynamic Simulation Approach:

Development of User-targeted Operational Crop-weather models with real-time crop-weather data as input

There are diversified users of agrometeorological information and weather-based advisories, both on long - term and short-term basis. User requirements may more often than not, pertain to specific crop species: e.g., knowledge about soil moisture status in the root zone at various depths needed for irrigation scheduling in corn crop in a current season (using real time weather and crop information), probability of assured rainfall or drought occurrence for two consecutive weeks in the cropping season for maize at a particular growth stage (based on time series analysis of rainfall data). Such requirements are presently met in a very qualitative way by the farmers themselves or by the agronomists or extension workers in agriculture, based on agronomic experience with a high element of subjectivity. These advisories need to be placed on more quantitative basis, eliminating subjectivity to the extent possible.

User requirement targeted models:

So far since the 1980's, dynamic simulation models have been tried for direct adoption with very few modifications in the various agroclimatic regions. Sufficient experience has been gained by now by agrometeorologists, in handling these models and their evaluation. At a few centers new genetic coefficients for crop growth have been determined but still these have been found to be of limited operational utility. Hence the immediate need is to provide facilities for development of operational models using sub-routines of the comprehensive systems models, which were mostly being utilized for estimating production potentials rather than for field operations based on real-time crop-weather data. The need is for the models to meet user requirements.

This area of developing **'user requirement targeted models'** is of specific interest and relevance to improvement of agro advisories being issued under the NCMRWF (DST) and ICAR, IMD agromet advisory programme currently in operation.

Innumerable requirements arise and for each of these, small simulation models or sub routine models of the larger "systems" models can be profitably utilized. More of the requirements usually pertain to specific agricultural operations to be carried out through the growing season and not always only for yield assessment. Sub routine models based on real time weather data are far more useful for meeting these specific needs within the growing season. A very simple example could be, to provide an answer to the question: "since rainfall occurred last night, should *I* irrigate the crop, if so, what is the amount of water to be applied?" Data input requirements may have to be kept to the minimum and limited to data accessible to the user. Efforts should be made to identify the likely requirements of the farming community from field experience and simulation models developed for formulation of such weather based agroadvisories, which can be made available at farm information cyber cafes.

Simulation Models as Forecasting Tools within a Crop Growing Season

Simulation models can be run in any current season with real time data from day one of crop germination. The model can get real time crop-weather data as input upto the date of current weather observations; for the rest of the period of crop growth, normal weather data can be given as input to estimate phenological events or grain growth rates and yields. Obviously, as the current data input component increases, the period of normal data input gradually decreases. Apart from normal data input, it is also possible to include options for the later part of the crop growth (that remains to be covered till harvest by current weather data input), to estimate effects of weather variations such as, possible unit increase / decrease in temperature or evaporation or rainfall occurrence at specific growth stages and obtain estimates under different expected scenarios well before harvest of crops.

So far, dynamic simulation models are not being put to this purpose in our country since we are yet in the stage of calibration of the models and validating them, which is, some sort of *post mortem exercise*. Once this phase is over, the above option can be easily adopted to make best use of the models by running the models in a current season with real time data input.

Development of EXPERT Systems:

As a follow up of the above information, operational models using real time data and EXPERT SYSTEMS can be developed for each of the major crops in the different agroclimatic zones of the country or even for smaller geographical units. Such expert systems can be developed to prepare advisories on "critical weather and sowing schedules, irrigation and fertilizer application, plant protection measures, crop /fruit harvest schedules" etc. The scope for expert system software in application of agrometeorology for agricultural operation is immense and unlimited.

Biometeorological Aspects—Livestock, Poultry and Fisheries

Animal – Climate Relations:

Output of dairy products from animals, output from the poultry, goats, sheep, exotic birds, animal growth and diseases affecting them, their living environments are known to be governed by weather conditions. Development of quantitative climate-animal relationships and efficient utilization of daily weather data for monitoring the various aspects, which at present can be said to be non-existent is a research priority.

Traditionally, the major climatic factors on which attention has been focused are: temperature, humidity, solar radiation and length of day. The effects of these climatic factors on reaction of animal physiological parameters have been studied by measurements of (a) animal's ability to promote heat loss by such means as increased evaporative cooling from the body surface, (b) its ability to reduce heat production by lowering its metabolic rate through more efficient energy utilization (c) its ability to put up with a rise in body temperature or with the consequences of compensatory reaction. Experiments are done in climatic chambers since field measurements often involves difficulties of interpretation in separating out the effects of climate from those of nutrition. In India, there are very few climatic chambers and infrastructure development should receive attention.

Water consumption, water intake, insensible perspiration (diffusion moisture, different from the moisture which has been actively secreted), protein intake, intra- and extra cellular volumes, plasma and blood volumes, body temperature, respiratory activity etc., of animals are all affected in relation to changes in air temperature and humidity. Significant seasonal changes had been recorded. These in turn, have profound effect on output of milk yield and several other animal products. Development of predictive techniques for assessment of milk yield or other products would be a thrust area. Some of the envisaged findings would be significant from the angles of product storage, transport, marketing and distribution. This is also of economic importance as some of the products are exportable commodities.

Several gross relationships between climate and its influence on physiological and biochemical aspects of animal behaviour have been worked out in the past on seasonal basis but a more intensive study on short period effects is needed. National dairy research institute, veterinary research institutions and universities had conducted several studies. For reasons unknown, interaction of their scientists with agrometeorological research centers till now has been minimal. For initiating and conducting relevant research projects, such an interaction is essential and is a priority area that needs to be explored urgently.

Fisheries – Ocean climate relations

Catch of fish is known to be related to ocean climate, upwelling and sinking processes near the coastal regions which are influenced by seasonal weather / climatic systems. This is one thrust area that requires attention by associating the Central Fisheries Research Institute with National centers of research in Oceanography or ocean climate. This has relevance to 'Indian Climate Research Programme' where projects are in operation for study of ocean climate and monsoon activities. Inland fisheries and climate relations in different seasons, is another area for investigation.

Positive correlation was established between southwest monsoon activity and oil sardine fishery along the southwest coast of India. With the change in climate and failure of rainfall (which usually brings water, rich in nutrients, from perennial rivers), there has been perceptible fall in fish production in many areas along East Coast. Predictive models are yet to be established between weather parameters and fish production both inland and the marine fishes.

Agrometeorology and Remote Sensing:

Remote sensing for estimation of crop acreage and crop cover for major crops at periodic intervals

Satellite imageries are providing information on crop cover through determination of various vegetation indices. Spectral characteristics of major crops and the crop parameters (growth phase, LAI etc.,) are being utilized to estimate crop yields also. These studies have to be intensified. Simultaneously, it is essential that from ground truth sampling of data from various agroclimatic zones, crop cover and yield estimates are made for advance determination of likely production in a given season as affected by major weather related events like thermal, moisture stress, damage due to disastrous weather events like cyclones, agricultural drought etc.

More important is to give thrust to research to develop capabilities of identification and demarcation of crop species, zones affected, intensity and spread of the area affected by aberrant weather conditions. Individual research efforts had been made at several locations in this direction but regional level studies are more relevant and these need to be initiated and strengthened. In this connection, it is also relevant to mention that regional level medium range weather forecasts with reasonable accuracy are likely to be available in the coming decade and it is imperative to strengthen research on regional level effects of disastrous weather events on crop conditions.

Remote sensing techniques for estimation of surface soil moisture through microwave techniques

Satellites using microwave bandwidths are in operation now. These are likely to be increased in number for estimation of soil moisture status under different land use patterns, on a countrywide scale. This information can be utilized to estimate moisture status in the soil profile through development of algorithms between surface moisture content and the profile moisture. This would provide information on soil moisture status for the different regions, based on which, irrigation schedule, irrigation water requirements and projected yield estimations can be done using crop-weather dynamic simulation models to assist agricultural operations. Being a promising technique, research thrust in agrometeorology should be laid on development of algorithms between surface moisture conditions with that in the different soil profile layers for the different cropping systems.

Remote sensing techniques in locating incidence, development and spread of agricultural drought

Crop spectral indices provide an indication of incidence, development and spread of continental drought. It would be possible in course of time to map out intensity and spread of agricultural drought over different parts of the country through satellite imageries and the aerial extent to which individual crop species are affected in any cropping season. Such early warning system in a current season would help in determining ameliorative action by way of crop contingency planning for drought conditions. Surface soil moisture maps through microwave remote sensing imageries would supplement this information on drought and can be beneficially utilized for advising mid term corrections or alternative cropping pattern based on crop-weather characteristics. Thus spatial information is becoming increasingly important and will probably become the dominant platform on which agrometeorologists will work.

Research thrust in agrometeorology should be on development of crop contingency plans based on crop-weather-soil drought intensity patterns expected during the cropping season. Dynamic crop–weather simulation models can be extensively used in such research.

Remote sensing techniques for locating flooded zones and their recession

Periodical remote sensing imageries can be utilized to demarcate flooded zones caused by heavy rainfall over cropped fields and their recession time. These are helpful in crop planning (choice of species, cultivars and other agricultural operations) involving agrometeorological considerations.

Crop contingency plans for flooded zones will have to be developed based on crop-soil-weather characteristics and the seasons in which such floods are likely to occur. Mid term corrections may also be possible by frequent monitoring and contingency plans of agricultural operation should include this aspect also.

Remote sensing techniques in locating incidence, development and spread of major crop pests and diseases at periodic intervals

Determination of spectral indices for identification of pest / disease incidence and spread over cropping zones are under way. In future, it is likely that satellite imageries are routinely issued at periodical intervals indicating the cropped zones affected by pests and diseases. Chemical spray schedules prepared on the basis of weather conditions around the crop environment can lead to minimal use of spray amounts by proper timing of spray application at appropriate height above ground.

Research on identification of favorable weather conditions for determination of spray schedules and characterization of micro climatic conditions in cropped zones for ground based sprays, (and weather conditions below 2-3km above ground level over cropped zones) should be intensified.

Climatic Change, Variations and Impact on Agriculture:

Monitoring of Effects of Climatic Variations / Change and Their Impact on Yield; Prediction of Crop Productivity in Relation to Shifts in Climatic Belts

Climatic change and variations, their effect on global warming, are under intensive study by meteorologists. However, research projects specifically devoted to study of impact of climatic change or variation, effect of latitudinal shift in climatic belts and their projected influence on cropping pattern and quantitative changes that may be brought out in yield potential, are meager. While meteorologists or climatologists have vigorously pursued studies on global climate changes and global warming, it is relevant for the agrometeorologists to pay attention to utilizing these results for studying their impact on agricultural production systems and develop adaptation strategies for crop planning. This activity will have to continue receiving attention in the coming two decades and beyond, since it takes so much time to substantiate the observed variations in output of agricultural products which most of the time, may be a result of the effects of temporary-short period weather stresses.

The expected changes in climate for India as projected indicate that increase in temperature in *kharif* season is likely to be less than that in *rabi* season; *rab*i rainfall may exhibit larger uncertainty whereas *kharif* rainfall is likely to increase by as much as ten percent. Such changes will affect agriculture considerably through its direct and indirect affect on crops, cropping systems, livestock, pest / diseases and soils, thereby affecting food security. Climatic change will have an impact on different crop management levels also with regard to fertilizer application, carbon sequestration, soil processes and water management and in realization of yield potentials. In all these areas agricultural meteorology has a role to play.

Impact of climatic change on agriculture depends on both the amplitude of such changes and agriculture's vulnerability to climatic variability. This vulnerability varies according to the region where cultivation is practiced and also changes over time due to adaptability of crops; such variations might sometimes be more relevant than climatic changes themselves. A few examples are: root crops are less vulnerable to rainfall variations than many other crops. Similarly Tropical tree crops are less vulnerable to rainfall variability than are the short-term crops. Analyzing the spatial and time variations of the vulnerability of different agricultural systems to climatic variations is needed.

Studies on agroclimatic zone-wise impact of climatic change and variations, shifts in rainfall, cropping zones, and consequent effects on land use pattern, cropping zones, thermal and moisture regimes need attention. Impact of climatic variations (short period effects) and climate change (prolonged period effects) are to be distinguished.

Forest and Agro-forestry Meteorology

Forest Agrometeorology:

Forest areas have their own microclimate and radiation penetration is one of the most important factors which has a bearing on moisture distribution below the canopy. Denudation of forests changes climate at a meso-scale in the neighbouring areas also. This is an important area for agrometeorological studies. Forest fires, is another significant area that needs attention, since there is increasing demand for prediction of favourable conditions for forest fire incidence, duration and favourable weather for ameliorative action.

Meteorology of the Agro-forestry:

Since the past decade, attention has been paid to expansion of agro-forestry for semidry areas and with reference to reduction in air pollution close to the urban areas. Also, "crop cafeteria" crops of several heights and spread grown in areas like Kerala state is a system for which no agrometeorological studies have been specifically made. In view of the demand and plans in the future for expansion of Agro-forestry, it is imperative that efforts should start now to understand the agro-forestry climate as a whole system. This poses problems in the sense of exposing multiple system of weather sensors, and integrating the results for the whole system and their interpretation. This is virtually an exploratory area in agrometeorological studies.

7.3. Agrometeorological Services to Agriculture

Crop Yield Forecasting:

Product yield forecast in agriculture is the ultimate goal with practical utility by whatever means it is done. Such forecast users range from the farmer, trader, economist, planner, byproduct manufacturer, food processing industry and those involved in storage, transport and marketing. Economic planning for the country is heavily dependent on yield forecasts more than a crop season ahead, if not a year. Successful long-range weather forecast, available a crop season, ahead is a prerequisite for a reliable yield forecast, which also involves crop planning. Short and medium range weather forecasts assist in agricultural operations.

Crop yield forecasting at all India level had been initiated since the 1920s or even earlier along with development of techniques for long - range forecast using parametric models. Crop cutting experiments, integrated with multiple regression, polynomial, curvilinear expressions had been in use for yield forecast at regional levels in the different seasons. Though in several cases, these are considered optimally unsatisfactory, a fair degree of success can be said to have been achieved. More research on the long and medium range weather forecasts, which aid crop planning and agricultural operations respectively is the need. Improvement in techniques of analysis, application of Global Climatic Models, understanding of ENSO (El Nino and Southern Oscillation) phenomena and their forecast are all involved. Added to this are the projected effects of global warming and climatic change on weather, and their impact on agriculture. This is a complex challenging area for meteorologists as well as agrometeorologists.

Presently, options are open to put the techniques of dynamic crop-weather simulation models to predict crop yield by running the models from day one of seed sowing. Current weather and forecast scenarios can be utilized together in a crop season to predict crop growth and yield through intermediate corrections between model output and actuals within the season regarding water balance, biomass, leaf area index, timing and duration of phenological events, and partitioning pattern of biomass. Close monitoring using simulation models is one hope but this procedure is required for each crop species grown in a region. Relations are to be established between heterogeneous observations in the farmers' field in a district and homogenous (controlled) experiments carried out at the research stations and integrating these two sets by developing appropriate technology. This is one approach on a small scale for an agroclimatic region. Dedicated groups of agricultural scientists are to take up this challenge.

This being a practicable option for yield forecasting using short and medium range weather forecasts, agrometeorological research and experimentation should be planned in this direction with interdisciplinary groups without waiting for perfect long - range weather forecasts.

Weather Based Agroadvisory Services

Weather forecasts and weather-based advisories for agricultural operations help in development of sustainable and economically viable agricultural systems and land use management. Both short range and medium range weather forecasts are being utilized for this purpose. Major objectives of these forecasts is that they can be employed for providing weather-based agroadvisories to the farmers in advance for undertaking farming operations based on the expected weather 2 to 10 days in advance. Presently (year 2006), 107 of the 127 proposed Agro Advisory Service Units (AASU) are in operation in the different agroclimatic zones all over the country under NCMRWF of the Department of Science and Technology.

In-Season Monitoring of Crop-Weather Information

***Introduction of Agro-Weather Map*:**

A systematic, organized and streamlined mechanism to develop database on real time basis, catering to both local and regional level has to be put into operation. With respect to weather conditions, synoptic maps are regularly put out and both local and regional forecasts are issued. On similar lines, crop-weather information needs to be monitored which means, *observation, communication and immediate analysis*, has to be arranged on a daily basis. Crop observation sites among the cropped fields have to be identified, and communication facilities provided for data transmission to a nodal research station like that at the agricultural university as a routine. Unlike weather observations, crop observations could be reported once in three days (unless special crop observations are needed for specific adverse weather situations) and a map showing crop situation for each major crop species can be prepared immediately after observations are received, if not every day, once in three days. These can be given the name **"Agroweather Maps".** The nodal agricultural research station should also have easy access to synoptic weather map every day for superposition of crop situation / observation maps for interpretation and formulation of weather based agroadvisories.

A genuine apprehension among weather forecasters could be that synoptic weather map may be improperly interpreted or used by the nodal agricultural research stations for issuing their own weather forecast. This can be avoided by having memoranda of understanding between the IMD and the concerned agricultural research station (located either at the SAU or ICAR institutes). Communication between the Regional/ State Meteorological Center and the nodal agricultural research station is an important link that can facilitate smooth functioning of preparation of crop situation maps and superposition of the synoptic weather map to evolve the agro-weather map. The nodal agricultural research station can use both the synoptic map and local/ regional forecast put out by the IMD and also the medium range weather forecasts issued from NCMRWF for framing weather-based advisories.

Establishment of such a system needs to receive priority consideration by all the organizations concerned and the modalities worked out without any ambiguity regarding jurisdiction for action.

Synoptic maps for nodal agricultural centres

Though medium range weather forecasts are issued taking synoptic and upper air weather into consideration, for better appreciation of the weather forecast and for several operational purposes in agriculture, availability of synoptic chart (with one or two upper air level wind or contour charts upto 2-3km for research and agricultural operations related to insect migration or air pollen) at agricultural research stations are considered as an essential requirement. With vastly improved communication facilities, this should not pose a problem provided the modalities are worked out between the regional centers of the national meteorological service and the agricultural research stations for communication of such charts or any related information as fast as possible in the day.

Future plans:

Future planned activities of the services to be provided by NCMRWF include expansion of the network of AAUs, increase in forecast period from the present 4 days to 7 days and daily issue, issue of forecast and agroadvisories on a regional basis. Research needs are to be directed towards increasing resolution of the forecast models, extension of forecast range for a month or a season, organizing support research in crop-weather modeling and EXPERT system for improving weather-based agroadvisories. These activities along with improvement in infrastructure and manpower are expected to result in providing quantitative and timely agroadvisories and improved dissemination needed for day-to-day agricultural operations. On-going programmes in this field of activity are to be strengthened by way of research, HRD and infrastructure facilities at NCMRWF, AAUs, and CRIDA in a coordinated mode.

Monitoring crop growth and Crop-weather diagrams:

For monitoring crop growth in any current season, for each crop species, preparation of crop weather diagrams or calendars is advisable. Examples of these can be seen in such diagrams prepared under the Crop- weather scheme in the country which was in operation from 1945 to 1970 with traditional crop varieties. In these diagrams, the times and duration of crop phases like sowing, tiller formation, flowering, grain-filling etc., recorded in every growing season for important crops in a specified region were given in a pictorial form and on a 'Standard Week' basis. Against each of the growth phases, the type of weather phenomenon for which weather warnings were to be issued was indicated. This is a practice that can be revived at several agrometeorological centres and AAUs in the country as a routine.

Post season monitoring and review of crop situation in relation to weather

Weather-based advisories provide an advance warning of impending weather, both favorable and unfavorable. The effects of the actually realized weather on crops at different growth stages must be analyzed which can provide guidelines on (a) where and in what weather situations did we succeed by forewarning (b) in what weather situations did we fail and could this have been avoided? (c) What remedial action can be taken to minimize such failure. This can be carried out agroclimatic zone wise. This can have several aspects: such as the nature of warning issued, incorrect advisory for agricultural operation, gap in communication, lack of lag time between actual occurrence of weather event and monitoring resources for action plan advised etc., The review in the post-cropping season can cover all these aspects and should be done as a routine at the end of every cropping season for each of the crop species individually, before one forgets the realized impact.

Early Warning System for Agricultural Drought

Drought Warning Forecasts Crop-wise, Region-wise, using Medium Range Weather Forecasts, Synoptic Systems and Satellite Images, on a Real Time Basis

Several significant efforts have been made in the past on the front of drought research. Most of it related to meteorological drought, which could be mild, moderate, severe or disastrous and several agroclimatic characterizations of drought for different states in the country have been made. However, since drought affects not only crop conditions, but also water availability for drinking and industrial purposes, grazing fields and fodder for animals, generation of hydroelectricity etc., research should be aimed at covering several aspects employing a holistic interdisciplinary approach.

"Drought cannot be defined" is the usual refrain but this perception should change.

Agricultural drought:

Specific efforts for identifying drought in individual crops and the growth stages affected have been very limited and have to be taken up as a research thrust. In relation to agriculture, in studies on moisture or aridity indices developed for the purpose of drought characterization, all crop species are usually clubbed together and drought affect on individual crop species is not brought out clearly. It is admitted that there are a few exceptions to this approach, but these are inadequate. The advantage of this approach (determination of agricultural drought in a growth season, separately for each of the crop species) is that personnel engaged in agricultural operations need not interpret a warning meant for general drought occurrence, which may or may not affect a specific crop species.

Drought criteria for paddy obviously would not be the same for sorghum. If only, the drought condition gradually turns disastrous in nature and widespread, since such a situation affects all crops and also all other activities in public life dependent on water, a general drought warning would suffice but would be of limited use in practice for agricultural operations.

Thus research efforts should be directed towards characterization of effect of drought on each crop species in the different agroclimatic zones both at local and regional level. Several studies at individual research centers are available but these need to be compiled as a distribution map on a regional basis for better utility. In any current cropping season, it is also necessary to develop drought-warning advisories for agricultural operations *crop wise, region-wise using current weather, synoptic maps, satellite images and medium range weather forecast*. This is possible if concerted efforts are made to define weather thresholds, compile agroclimatic information, pheno-phase based characterization of weather in relation to crop species and use of weather parameter based dynamic simulation crop-weather models using real time data.

Crop Contingency Plans and Schedules—Review after every five years

Several agricultural universities, State directorates of agriculture, Central research institutes of ICAR had been evolving crop contingency plans and suggesting ameliorative measures for meeting impact of aberrant weather situations on crop performance. These need a comprehensive review, agroclimatic region-wise and updating after a review of its success/ failure once in five years with wide publicity to such contingency plans instead of waiting for a calamity to occur. Alternative strategies are to be worked out keeping in view the necessity for sustainability of agricultural production and feasibility of application of such contingency plans in practice, at affordable cost. This is an interdisciplinary activity but centered on weather situations. Dynamic simulation and systems analysis can be profitably utilized for this purpose.

Weather Based Forewarning Systems for Pest / Disease Outbreak and Control Measures

Pest / Disease – Climate relationships

Pest disease surveillance programs in the past have helped agricultural scientists to delineate hot spots of several pests and diseases. Presently maps of the distribution of pest and diseases over the country are being prepared. With weather systems following different tracks every year, prediction models developed till this day, in the form of regressions, succeed in one season and fail in another season because of their location and time specificity.

Standard format for data collection

Non-uniformity in data collection is a major drawback encountered for utilization of historical data since no particular format was evolved in the past for this purpose. Also, information on leaf wetness duration, which is an important parameter, is absent. Thus there are several gaps to be filled up in this area of study. Very recently, a promising beginning has been made to develop weather-based pest/ disease warning systems under the NATP of ICAR covering major crops and pest / diseases affecting them wherein, data collection has been made systematic as per an agreed format for all locations in the country engaged in this program. It would be beneficial if researchers outside the NATP also follow this format with some small changes if required, through mutual discussions. At least such a step would ensure uniformity in data collection all over the country and a minimum data set is identified with freedom for optional / additional data collection for specific projects.

Laboratory studies on crop pest / disease and climate relationships

Several gaps exist in this field. Long term field observations on crop pests/ disease and weather data do not seem to fully serve the purpose. Pest-disease development into epidemic proportion being ***dynamic in nature***, statistical relations developed earlier, many a time, fail to provide an answer for day-to-day monitoring of pest / disease development in relation to day-to-day changes in weather, which are also ***dynamic***. In cases where the growth cycle phases of the pathogen / insect involves a period of more than a week or so, it would be possible to utilize laboratory determined pest / disease organism-weather relations, for field operations. "Climatically favorable" days for incidence and growth during life cycle of the organism need to be identified by day-to-day monitoring of crop-weather-pest-disease conditions in relation to laboratory observations and related threshold values of weather.

Threshold values of weather elements for pest / disease events

Several gaps exist in this area though, for a few parts of growth cycles of an organism such threshold values have been determined earlier through both laboratory and field observations. Agroclimatologists, plant pathologists, entomologists should sit together to chalk out a program to fill up gaps after compilation of the existing information on insect/ pathogen-weather thresholds at different growth stages of the life cycle of the organisms.

Temperature induced stress can cause changes in plant physiology resulting in changes in the levels of chemical defence and nutritional quality of the host. Insects feeding on such plants would have altered growth, development, reproduction, and survival behavior.

Water-induced plant stress has also similar effects. Microclimatic changes within the crop, which could affect insect pests, is another aspect for study.

In predicting insect distribution in a changed climate the use of Bioclim (comparing patterns of annual meteorological data) or Climex (how a species experiences climate week by week during the year) approaches are known elsewhere. These approaches need evolution of clear definitions of weather thresholds. Close interaction of climatologists with entomologists and plant pathologists could promote increasingly effective strategies in such studies.

Integrated Pest Management and Weather

Integrated pest management (IPM) programs have been undertaken in the country during the past decade, which showed that weather-based models are the need of the hour in limiting possible excessive usage of insecticides, pesticides and fungicides. Presently, in the weather-based approach, thumb rules have been developed which are giving encouraging results. In future sustained efforts are required in the direction of in-season daily monitoring of pest disease status, data collection in a standard format, recording of leaf wetness duration and development of prediction models and gap filling experiments.

Microclimate and use of synoptic surface and upper air charts for pest/disease control operations

Measurement of microclimate in the cropped fields, use of surface and upper air synoptic charts upto 2-3 km are needed. Except in the case of locust studies and brown rust on wheat, such information had not been generated in the past. This is a priority area for development of successful models on early warning systems specific to certain insects and species that are carried by the air stream or those whose movement is influenced by low-level cyclonic and anticyclone circulation.

7.4 Agromet Instruments and Observations

Instrumentation for Agrometeorological Research:

Development and Fabrication of instruments for agromet work with emphasis on development of sensors, creation of facilities in the country for their test and calibration

This is a thrust area proposed for the 10th plan period and should continue for the next two decades also. For almost all equipment with spot reading or automatic recording facilities used in agrometeorological work, we are depending on imports even today. As stated earlier, urgent need is for encouraging development of various types of sensors, their testing, and calibration. The instruments used for the fieldwork get exposed to crops, dust and weather elements throughout the year; frequent calibration and replacement is a primary requirement. Presently, both manufacture and calibration facilities are very few or rather non-existing. Waiting for imports results in loss of data, discontinuity in observations and waiting time, not to speak of freight and insurance costs sometimes exceeding the cost of the sensor itself.

Data loggers work for a long time without any instrumental complications or breakdowns. It is with the sensors, which wear out especially as they are exposed to climatic conditions and dust in the cropped fields that researchers face problems in replacement, which are mostly to be imported. It may not be out of place to mention here that even a very accurate maximum or minimum mercury thermometer is difficult to procure within the country though costs are not very high. PAMC on Agrometeorology (DST) had earlier in the 1990's explored the possibility of encouraging manufacture of weather sensors within the country but these attempts have not been successful. This is one area that needs to be pursued again to find a solution though it may not be apt to term it as a thrust area for research but as the one, which facilitates research.

Weather sensors, indigenous production and import substitution:

There is no doubt that sensors are a recurring requirement, though no survey has perhaps been conducted even to see how many imported research instruments are in working condition and how many are not, simply because of non-availability of sensors off-the-shelf within the country. This is true not only in the field of agricultural meteorology, but also with those of medicine, molecular biology, geophysics to name a few, which utilize instruments with common principles of measurement of the environmental conditions but differing in specifications for compactness, sensitivity and resolution.

Projects to achieve self-sufficiency in sensors have to be taken up within the country which would save both loss and discontinuity in data, wait time, and foreign exchange, manual effort needed to import these items. This is one of the most important priority areas that can be taken up since immense trained manpower in engineering, technology, and manufacturing capabilities are available within the country. Industrial houses in the country do not seem to have taken interest in this area, as they feel that quantum of sales cannot be guaranteed by any organization. With several programs in agrometeorology in operation since 1980s, there is an increasing demand.

Leaf wetness duration measurement and estimation

For the incidence, multiplication and spread of crop pest /disease organisms, the most important weather parameter is the 'duration of leaf wetness'—how long has the leaf been wet during a day or night with a thin film of water. Thus even 'trace' of rainfall, fog or dew parameters are significant for this process. This information is considered most crucial by plant pathologists and entomologists. Most of the time, recourse is taken to correlate relative humidity, a non-conservative parameter, with pest/disease population. Leaf wetness can be estimated by indirect methods though measurements are the best option.

Leaf wetness duration recorders have been developed abroad several years ago, but in our country we have to depend on indirect indicators of leaf wetness from weather data. Mathematical expressions are available, empirical techniques using temperature, humidity, dew data have been developed but these are yet to be tested and validated. Hourly weather recordings also are available at a few places, but these remain unutilized for this purpose of estimating leaf wetness duration. The reason could be the prevailing impression that inclusion of the simplest weather parameters *viz.*, temperature and humidity would sufficiently take care of the wetness parameter and correlations obtained are statistically significant. However, the regression approach cannot be expected to replace actual measurement of leaf wetness duration with automatic recording facilities—recorded leaf wetness. Being important for pest / disease development predictions, this is a high priority area which deserves thrust.

Automatic Weather Station Network for Agricultural Operations:

Presently several agricultural research institutions have imported automatic weather stations from different manufacturers abroad. There is a feeling among scientists that these could function as a network so that data can be exchanged on-line if necessary. Such networking is also considered by some to be useful for regional scale studies or agricultural operations. Near-real-time hourly surface weather data from such automatic weather station network can be used for irrigation management, livestock management, forestry, crop characteristics, pest management etc, This could be a goal for the next decade.

While this is true in principle, the following constraints do not permit such a networking at the present stage.

1. The number of automatic weather stations presently operating in the country is insufficient for forming a viable network.

2. There is no uniformity in timing and frequency of observation.

3. There is no uniformity in exposure of the automatic weather station. Some are installed in the agromet observatory compounds and others are installed in cropped fields. This is understandable since the weather stations have been procured with specific research projects in view.

4. As mentioned earlier, due to non-availability of sensors within the country, at several places, data collected could be incomplete and discontinuous for months together defeating the very purpose of automation.

5. Sufficient trained personnel are not available who can maintain and ensure an uninterrupted data collection. Repair or replacement facilities are not available within the country.

6. Presently the data output is underutilized except for the data that may be collected for intensive observation periods where the need is felt.

The following points require to be debated at a proper forum before automatic weather station networking is considered and established in the next two decades in the country.

1. A survey is to be carried out for assessment of requirement for such a network in view of the manned observatory and agromet observatory network already functioning in the country, which is generally considered satisfactory.

2. What are our needs for intensive data collection (hourly surface weather data every day) and who are the users (some uses have been mentioned above) for this intensive data output?

3. Should this be a National network or comprise of smaller networks for each agroclimatic region or for a State— which would be more manageable?

4. Is such surface weather data a general requirement or continues to be a requirement for specific research projects such as micrometeorological studies?

5. Would it improve the present services rendered by the IMD, and agrometeorological needs for operational agriculture, if all manned observatories are supplemented or replaced by establishing automatic weather stations, which can form a single or several manageable networks?

6. Should the installation of automatic weather stations be confined to data collection from inaccessible and remote areas, and for specific research projects as is the case now?

7. Is it feasible and advantageous to network automatic weather stations installed in agricultural research stations, which would supplement the manned surface weather observatories of the national meteorological service?

8. We have sufficiently advanced facilities for data dissemination from any proposed automatic weather station network and these are adequate.

9. Networking of automatic weather stations would facilitate undertaking regional agricultural operations as it would facilitate regional analysis. In the USA near-real time hourly surface weather data from such automatic weather station network is used for irrigation management, livestock management, forestry, crop characteristics, pest management etc, where about 25-30 stations in a state are networked. However such management packages are yet to be developed in India for the various regions.

10. Faster dissemination of hourly observations (once or twice in the day) on surface weather elements is one of the advantages of an automatic weather station apart from eliminating the subjectivity factor in observation.

11. A significant query from agrometeorological point of view to be decided is: Either now or in the future, do we need hourly surface weather data for agricultural operations in our country? We need hourly data for research and for local agricultural operations to a limited extent and not necessarily in a network mode. Reducing the time lag between time of observation, and its communication to a central location and its access to various user agencies at the earliest possible hour in the day seems to serve our purpose. At present, such a facility is not available to users outside the national meteorological service. This needs priority consideration and action.

12. With more sensors exposed at different heights, and specified non-conventional observation frequency, data from micrometeorological tower has more utility for providing database for research in air pollution effects on crop canopies, identification of time of the day and height above ground for determining the spray schedules of insecticide, pesticide, fungicide etc., based on real time weather data either at a single location or over a network of locations with geographical contiguity.

13. An automatic weather station by itself is not a replacement for a micro-climatic tower needed for research and some of the agricultural operations.

14. Micrometeorological tower observations would facilitate study of favorable crop and weather conditions for incidence of pest / disease within the crop canopy. This information is not available at present. This is a research requirement.

15. Whether it is automatic weather station or micrometeorological tower, we have to depend on imported sensors for several years to come unless manufacturing and calibration facilities are created within the country. While it may be relatively easy to create calibration facilities, we have not been able to encourage manufacture of the sensors within the country.

Micrometeorological towers:

As far as automatic weather stations are concerned, they can be installed where hourly observations are considered as a specific requirement for agricultural operations or for purposes of research. At nodal agricultural research stations, as a supplement to manned agromet observatories, establishment of micrometeorological towers would be a multi-purpose utility— for research on energy balance, land-atmosphere surface processes and transport phenomena (moisture, heat, CO_2, wind, pollutants, pesticide / insecticide dissemination close to the ground etc.,) and for practical application of determining time schedules of pesticide, insecticide or foliar spray of nutrients more effectively to take advantage of weather conditions which improve their efficacy of spread within the crop canopies, leading to reduction in wastage of the chemical. It is well known that temperature inversion level and wind velocity play an important role in making chemical application more effective.

These are points to be debated for planning automatic weather stations in the country as also the installation of micromet towers.

7.5 Agromet Data Bank: Database Management

Adequacy and use of agrometeorological data

Users require a vast range of agrometeorological information cutting across various spatial and temporal scales. Data required for preparation of climatic statistical summaries and currently available in the country are considered adequate. The available data had been extensively utilized for computing potential evapotranspiration, rainfall probabilities, climatic water balance, drought probabilities and also for correlation of long time series data with several crop parameters viz., yield regression models, disease/ pest regressions, delineation of agroclimatic zones of India and several such purposes. Data will continue to be acquired for periodic updating of the analysis made earlier.

For analysis using agrometeorological approach (studies on short period adverse weather and crop performance, and various transport processes) however, database in the country is meager and inadequate. The most valuable information for management purposes is the 'recent' data. The speed at which the data can be recorded, transmitted, processed, checked and made available increases the value of the information. Data base development in the country had been progressing depending on advances made in instrumentation from time to time and their import, depending on needs of individual research projects. In recent times since the 1980's however, since an 'All India Coordinated Research Project on Agricultural Meteorology' (ICAR) has come into operation, efforts have been made to equip different state agromet centers under the scheme with sophisticated equipment in a small way. However, this has been a slow and gradual process.

Uniformity and standardization of equipment and observation procedures:

A review at national level is required to bring out some uniformity and standardization in the type of equipment procured regarding the specifications, functions, quality and stability of calibration and observational procedures. Such an exercise would be useful since several research objectives are common to all regions in the country— only differing in the crop species raised or season in which it is sown. For illustration, net radiometers, soil heat flux plates, neutron soil moisture meter, infrared thermometers, leaf wetness recorders, diffusion porometers photosynthesis measuring apparatus, pheromone and light traps (used for insect population studies) etc., which are used in several agrometeorological research projects can have some commonality with regard to exposure in and above crop canopies, observational and recording procedures.

Apart from procuring these equipment, development of manuals of observation procedures and maintenance of the equipment allowing flexibility for deviations necessary for achieving objectives of specific projects, appears to be the need of the hour. The above steps would ensure authenticity and uniformity of data acquired and recorded for use by other users, apart from those involved in any specified project through data exchange.

***Agrometeorological database*:**

The most basic and important activity needed for both research and operational programs in any discipline for scientific study is the generation of database. Availability of a proper database is a major prerequisite for studying and managing several processes in the soil-crop-atmosphere continuum in relation to agricultural, forestry and livestock production. Building up of database on weather, agronomic, soil, pest/ disease, animals, livestock, poultry, horticulture, forestry, plantation crops etc., is of first priority.

The acquisition of pertinent agrometeorological data, processing, quality control, archival, timely access and database management are important components that will make the information valuable for use in agricultural research and operational programs. Since the collection and use of agrometeorological data depends on several specific and defined purposes from several treatments in field experiments, the design for data collection, accuracy, and management of data are on a different footing than that of a generalized climatic database.

Varied nature of Agromet database

Agromet database consists of manual observations, automatic weather stations, remotely sensed data with a wide variety of time and space scales—from seconds to days, weeks to months, at micro- meso- and macro scales of very different types of land use—from bare soils to cropped fields and agro-forestry systems. It also depends on specific user requirements. Extensive facilities both by way of equipment and personnel are needed for successful management of such a varied database. In agricultural research, demand is more for derived data such as probability statistics, water balance and drought indices.

Data Bank in Agrometeorology

A data bank in agrometeorology is functioning at CRIDA at Hyderabad. Currently it has been acquiring data from the experiments conducted under the All India Coordinated Schemes of ICAR on Agrometeorology and Dry land Agriculture. Data are being scrutinized, archived and a web site has been launched for dissemination of the data. Software has been developed to compute derived parameters such as water balance, probabilities of rainfall, degree-day summations etc.,

It is necessary that weather and crop data from sources other than the two schemes mentioned above – Other ICAR Coordinated projects, ICAR institutes on all crop species (cereals, pulses, oil seeds, plantation, horticulture and commercial crops), animal and veterinary institutes and SAUs are communicated periodically to the data bank in agrometeorology as a routine. For the benefit of all concerned, a copy of weather, phenology, soil moisture, crop yield data (including relevant information and other yield data on animal, livestock, poultry products etc.,) compiled by the respective coordinated schemes / institutes can be communicated to the data bank in agrometeorology as a routine.

The exact type of data to be communicated and the format can be decided by the respective Institutions / Universities in consultation with the scientists manning the Agromet Data Bank at Hyderabad. This may need strengthening the personnel and updating or upgrading database management facilities at the Data Bank at CRIDA by ICAR from time to time. When studies on impact of climatic change and variation are being planned on a large scale, action is also needed to locate past data recorded by the several institutes, for archival at this centre.

7.6. Training and Capacity Building

Human Resource Development in Agricultural Meteorology:

Training facilities

Training of personnel in meteorology, climatology and agricultural subjects both (basic and applied aspects), is an urgent need that was recognized by the National Commission on Agriculture but yet to be fully realized. Training facilities in agricultural meteorology / agricultural climatology in the country are available at different institutions as follows: (a) India Meteorological Department (Agrimet Division, Pune), (b) Indian Agricultural Research Institute, New Delhi (Division of Agricultural Physics), (c) State Agricultural Universities (Departments of Agrometeorology or Agronomy/ Physics), (d) Centre for Advanced Studies in Agricultural Meteorology (CASAM, Pune), and (e) Andhra University, Waltair. All the above institutions / universities, except the IMD provide training in Agricultural Meteorology leading to award of degrees at Masters and Doctorate level (M.Sc., or/and Ph.D programs). India Meteorological Department provides training at various levels for in-service personnel starting from observers to field officer levels in the respective State Departments of Agriculture.

Besides these, there are sponsored short term training programs, relevant to Agricultural Meteorology for in-service scientists supported by ICAR (summer institutes), DST (SERC Schools). Special multi-institution training programs in Agrometeorology are also organized to cater to the personnel employed in the AASUs for weather based agroadvisory services with special syllabus.

Agricultural universities mostly cater to teaching and extension activities and the personnel are heavily burdened with both undergraduate and post graduate teaching which is almost a whole time job especially with undergraduate teaching, examinations, assignments and their evaluation. This, as experience shows, leaves very little time to the academic staff to seriously devote time to vigorous pursuance of research activities except by way of limited thesis work required under the post graduate programmes of M.Sc/ Ph.D. candidates. This is where additional support through sponsored training programs from DST, NCMRWF and State Governments, Department of Space, Department of Environment and other such organizations has come to the rescue of the personnel at the SAUs, apart from the routine support provided by ICAR. A draw back of these training programs has been in the post-training activities assigned to the trained personnel. At least, a three-year stint in the area of training is not ensured by the parent institute, perhaps due to local logistic problems of promotion and posting policies. This has been a cause for concern.

Departments of Agrometeorology in State Agricultural Universities:

The progress of post-graduate teaching programs at SAUs has been slow. While the National Commission on Agriculture, as early as the year 1976 had recommended starting of independent departments of Agrometeorology in all the Agricultural Universities and at selected ICAR Institutes, out of 25 SAUs today such departments are functioning only from 9 Agricultural Universities leaving a majority of universities without such facilities. Even out of these, Ph. D. level teaching and training programs are yet to be initiated at several places.

Thus there is a dearth of fully trained personnel in Agrometeorology. Departments of Agrometeorology may be opened in the remaining SAUs at the earliest with the support of

ICAR. Several avenues for trainees in this disciplines in the future is ensured with expanding activities of AAUs, Departments of Agrometeorology, and demand for personnel in SAC, NRSA, DOE, NGOs, consultancy services and outsourcing projects needing agrometeorological support.

***Syllabus at graduate and postgraduate levels*:**

In spite of recommended common syllabi in agrometeorology drafted by ICAR academic committees, there appears to be lack of uniformity in its application at the different SAUs. This is because of (a) identification of different core courses in the different universities (b) non-opening of separate department for Agrometeorology (c) multiple areas of interactivity with agrometeorology and agroclimatology (from Agronomy to agricultural engineering to agricultural extension) (d) large number of optional courses to be taken within credit requirement.

Best option is to provide core course training in basic meteorological principles relevant to agricultural meteorology, basic climatology, micrometeorology and agroclimatic analysis, selected courses in agricultural statistics, software development and instrumentation to postgraduates undergoing training in Agrometeorology as Major. Optional courses can be prescribed from the allied disciplines pertaining to the thesis problem chosen by the candidate. For the candidates from allied disciplines desiring training in agrometeorology or agroclimatology, interactive program of study and syllabus may be considered as detailed below.

ICAR has provision for a periodical review of the syllabi at undergraduate and postgraduate teaching programs and the next review of syllabi can take these into view.

Interactive programmes in allied disciplines

The users of agromet services and data belong to a number of widely differing disciplines. Agrometeorology and agroclimatology personnel have to interact with scientists of several different sister disciplines in agriculture and to comprehend each others' point of view, it is essential to start **interactive programs** i.e., training of agrometeorologists in selected areas of plant physiology, agronomy, irrigation and soil science, plant pathology, entomology, agricultural engineering, horticulture, animal sciences etc., to name some. Joint teaching programs and integrated syllabi—— syllabi containing agrometeorology and each of the allied agricultural disciplines relevant to each other separately, and relating to weather-based agricultural operations would be most appropriate. Syllabus has to be carefully designed so that entomologist or pathologist need not be burdened with all topics in agrometeorology and *vice versa*. Only topics relevant to work of both streams, which aid interdisciplinary research, teaching and extension may be considered for inclusion in such syllabi.

***Course content in agrometeorology for allied agricultural disciplines*:**

Also, since credit system of teaching is followed in the agricultural universities, the candidates need not be burdened for the whole year for these joint courses. One common syllabus in agrometeorology or agroclimatology cannot be envisaged for all agricultural scientists at M.Sc or Ph.D. level (though it can be relevant at graduate and undergraduate level). To cite an example, the whole of entomology or whole of agrometeorology need not be taught to either of the streams, which are expected to work together and similarly with other disciplines in Agriculture. The point to note is that it may not be desirable but also futile to impart training in agrometeorology/ agroclimatology to a common group consisting of agronomists, pathologists, entomologists, horticulturists etc., at postgraduate level, since a feeling of irrelevance of the program creeps up among the scientists from different streams of specialization at post-graduate level or among in-service trainees who usually are at postdoctoral level.

A better proposition would be to conduct short-term training courses cum collaborative interactive workshops with small groups who have fairly a common interest (targeted groups) such as (a) Irrigation Engineers & Agronomists, Soil Scientists and Plant Physiologists, (b) Entomologists, Pathologists and Plant Protection officials, (c) Agricultural extension experts and field-workers, (d) Statisticians and Scientists concerned with crop yield predictions, (e) Cropping-Pattern Planners, policy makers, etc. In the above, top priority must be given to the training of persons in the interpretation and use of Agromet Advisories; also, requirements of the different groups for the type of agromet information they need to acquire are to be clearly identified. Such programs can be designed and organized by mutual consultation among concerned scientists from provider / user organizations such as DST, ICAR, IMD, and State Directorates of Agriculture, and SAUs.

Capacity building for developing dynamic simulation models

In this connection it is not out of place to mention that while scientists in the agricultural institutions have gained experience in applying the crop-weather simulation models developed abroad, several of them lack software development skills which is a serious limitation in thoroughly understanding or developing source codes of the crop-weather models. Intensive training has to be provided in writing programs in Fortran, C++ and CSMP and other simulation languages, which are frequently used in Agrometeorology.

Textbooks, Manuals and Reports in Agrometeorology and Agroclimatology:

There is lack of teaching material in agrometeorology/ agroclimatology. A few textbooks by Indian authors have appeared since 1990s but these are not presented in a structural mode. Such textbooks are not available even in the international market. Presently teachers taught depend on the notes culled out from research papers published in journals or that passed on from the teachers to students. Unlimited scope exists in this field at present. Lecture notes supplied at summer institutes and training programs are the material that is prepared now—these are not used and forgotten by the trainees once the training program is over.

Maintenance, care and upkeep of instruments used in agrometeorology also need guideline material for frequent consultation by scientists. Such guidelines ensure uniformity in exposure of instruments, recording of data and other computational procedures.

Agroclimatic analysis is another area in which reading material and procedures for computation of various derived parameters along with exercises with practical examples will go a long way in ensuring quality analysis.

Audio-visual aids in teaching (not only projectors etc.,) but table scale models, films, video programmes for understanding certain concepts and practical application is an area that needs to be promoted. All forms of study material are needed.

7.7 Linkage between National and International Institutes:

Good coordination has been achieved in linkage with national and international institutes with respect to programs in agrometeorology. DST, ICAR, IMD, IITM, IITs, IISc., SAC, SAUs are some of the national organizations which have been supporting research projects, workshops, seminars and training programmes at various levels in agrometeorology. At

International level, the linkages with ICRISAT, FAO/UNDP, WMO, ACIAR. INDO-US program in Agrometeorology with AICRPAM (ICAR), UNDP assistance for establishment of CASAM in the Marathwada Agriculture University, and training in Agricultural Meteorology /climatic change studies, ACIAR (Australia) with TNAU (Coimbatore), IGAU (Raipur) have proved useful in exchange of experts and scientists, training, augmentation of instrument facilities, and conducting seminars.

However, these have been few and far between, considering that activities in agrometeorology had been initiated in the 1930s in the country. With several advances made in the field of agrometeorology to keep up pace with the rest of the world, these have to be augmented through identified and specialized programmes. Global warming, climatic change, simulation modeling, air pollution effects on crop productivity in which research activities are expanding some of the areas where national and international exchange and linkages with advanced institutes will be beneficial to our scientific community.

VISION FOR NEXT TWO DECADES IN AGROMETEOROLOGY

8.1 Introduction

The scope and purpose of agrometeorology and agroclimatology, is to "apply every relevant meteorological skill to helping the farmer to make the most efficient use of the physical environment with the prime aim of improving agricultural production both in quantity and quality". The management action suggested by agromet services through weather-based agroadvisories must either lead to mitigation of a potential negative effect (e.g., drought, disastrous weather events) or build up on a potential positive effect.

Scientific knowledge keeps on advancing through innovations brought out by new developments in observation, measurement and communication technologies along with technological changes in the farming practices and one should keep pace with these. Significant changes have come about by way of addition of new tools for observation (from manual to satellite data collection) and analysis (from slide rules to super computers). Weather and climate themselves, as is evident from the studies on global circulation patterns, have been constantly changing throwing new challenges in harnessing the natural resources towards achieving sustainable agricultural production.

Monsoon activity, El Nino, La Nina, Southern Oscillation and ENSO have become the buzzwords affecting daily life in the country through manifestation of floods and droughts of unknown periodicity, with their impact on agriculture and economy of the country. Increased human activity all over the world purportedly is said to have resulted in increased air pollution and 'Global Warming', which is expected to influence the quantitative aspects of the hydrological cycle through increased / decreased rainfall, evaporation, carbon dioxide content, all of these having significant impact on agricultural production as also the quality of life.

The future thrust areas for research, training, extension and other related activities in agrometeorology should have relevance to these changes both in available technology and changing climate and their impact on agriculture. After an extensive review of the past and present activities in agrometeorology in the country and assessing future requirements for agricultural operations (including horticulture, livestock, animal husbandry, poultry, fisheries etc.,) through questionnaires and status reports from several peer scientists dealing with agricultural production, this vision 2020 for agrometeorology detailed below has been evolved indicating both major and minor thrust areas, an action plan and what is likely to be achieved in the next two decades by streamlining our activities.

8.2 Brief Overview of Status of Research in Agrometeorology

After more than six decades of starting of the activities in the discipline of agrometeorology, it is only essential that we should take stock of what has been achieved, whether the goals set up had been realized, if so, to what extent, are there any gaps to be filled up and what are the thrust areas in which research and other activities are to be pursued in the coming decades.

Qualitative knowledge had been built up in every branch of this discipline over the centuries but quantitative relationships specifically in our country have rather been very meager. Stated briefly, the reasons for this are not far to seek:

1. Qualitative relations can be built up with field experience and statistical analysis of numbers (field observations and data) gathered over a period of time but an element of subjectivity, location and time specificity are inherent in such relations.

2. Study of Agrometeorology has been systematically organized in the country in the nineteen thirties and forties but availability of instrumentation and equipment for measurement of crop-weather interactions from within the cropped fields have been very limited until the microprocessor and battery operated equipment for recording data continuously became available in the recent decade or two.

3. Earlier in the nineteen fifties, electric power-operated continuous recording equipment occupying large space and confined to the observatory building rather than to the cropped field became available at prohibitive cost and measurements could not be replicated at several locations.

4. For several years dependence has been on visual recording of data in the observatory rather than within the cropped field.

5. Most of the scientific studies depended on the data provided by the manual recordings available from the observatory (on temperature, humidity and wind) twice a day only and resort had to be made for estimation and interpolation. e.g., radiant energy could be estimated with reasonable accuracy for periods representing a month or a fortnight as the interval, though, hourly observations are needed for understanding diurnal variation in detail.

Consequently statistical analysis has been the mainstay in almost all studies (it continues to be so even to day for drawing inferences about crop-weather relations. Both weather occurrence and crop growth response being dynamic in nature, agroclimatological approach has given useful but only empirical or qualitative results for day-to-day application. The limitation imposed by this approach can be understood if we examine the magnitudes of weekly rainfall variability in our country and probabilities of occurrence with which one could work out only generalized relations applicable at specific locations and on averaged time scales. Obviously, in a given season with adverse weather lasting for four days to a week period, these are not absolutely representative results and hence the handicap of their applicability for day-to-day agricultural operations. This is sufficient reason to supplement this information on climatology with studies on agrometeorology— scientific study of specific relationships of universal applicability, based on mathematical analysis of physical and physiological processes of crop growth, in relation to influence of ever-changing weather and environmental conditions over short periods.

Unfortunately in our country we are lagging behind in this. The first priority would be to create conditions and provide appropriate training to open up this branch of study (Agrometeorology) for establishing crop-weather relations on a quantitative basis avoiding the location, time and crop cultivar specificity and subjectivity inherent in the statistical and empirical techniques for model development. There are several factors to be looked into for effective utilization of the various services that can be rendered using agrometeorological techniques.

Future directions

In this context thrust areas in agrometeorology are:

1. Integration of results from time-series analysis based on historical crop-weather data,

with current crop condition and forecast weather situations both at local and regional level for formulation of weather-based agroadvisories.

2. Development of models for early warning systems to cover all types of stress caused due to aberrant weather.

3. Organization of crop data collection and on-line transmission facilities from a network of crop observation posts (similar to weather observatory network stations) to be operated from selected spots in the cropped fields; to relate satellite observations validated by ground truth. These should lead to preparation of "Agro-Weather Charts" (on the analogy of synoptic weather charts) including information on both crop conditions and weather on a single map, as a routine.

4. Immediate analysis of this data for monitoring crop-health (e.g., plant-soil-water status, pest-disease stress, thermal stress etc.,) and crop-environment interactions for advising agricultural operations on a local and zonal basis. This should be a daily activity in relation to short and medium range forecast weather.

5. Collation and compilation of agrometeorological information (Definition of agrometeorological thresholds) for each of the major crops from available literature supported by laboratory and field research to fill up gaps in such information where required. This is an essential requirement for any analysis.

6. Phenology based agroclimatic characterization of climate and related analysis for each crop species for early, medium and late sowings is essential since a generalized climatic analysis now available cannot meet the user requirements. High priority is to be given to define phenological terms and record the events.

7. Monitoring of weather systems on synoptic scale (depressions, cyclones, heat and cold waves, flood / drought producing situations etc.,) and crop conditions for development of region/ zone-based risk management strategies and operations in agriculture, using remote sensing techniques and ground truth.

8. Studies on impact of climatic change and variations on crop planning and productivity need to be intensified.

9. Promotion and establishment of manufacturing facilities indigenously, for sensors of weather elements used in agrometeorological research. This is a high priority area. At present we are entirely dependent on imports; creation of such facilities would lead to import substitution and avoiding breaks in the observations and database.

10. Development of early warning system models for identifying incidence, growth, intensification and spread of insect pest and diseases in crops / animals in relation to weather and plant factors.

11. Use of crop-weather simulation models and development of EXPERT Systems for day-to-day weather-based agricultural operations using real-time data.

12. Strengthening of education and in-service training in agricultural meteorology is a priority area. Introduction of 'Diploma and Vocational Certificate Courses on Operational Applications of Agrometeorology' should also form part of this program.

13. As part of human resource development, Departments of Agrometeorology should be

established in all the SAUs and national institutes dealing with agriculture, as recommended by National Commission on Agriculture as early as 1976.

14. Development of risk management strategies (for drought, flood, heat-wave, cold-wave, hailstorms, thunderstorms, cyclones and other aberrant weather situations) based on probabilities of weather events derived from historical data integrated with current weather events. Cost benefit ratios, and field applicability may be assessed.

15. Development of strategies and contingency plans for mid-season corrections in irrigation scheduling, integrated pest and disease management and any other related operations during aberrant weather situations like droughts and floods, heat and cold stress.

16. Determination of optimum times of the day for scheduling chemical sprays based on micrometeorological profile (wind and temperature distribution with height). Spray schedule has to consider synoptic weather situations and their movement with time and in space, for effective application and economic use.

17. Emphasis to be laid on use of dynamical techniques for analysis of crop-weather interactions rather than purely basing them on statistical analytical approaches in view of the nature of high variability in weather elements in the tropics and sub-tropics. Such dynamical simulation models can also imbibe statistical regression expressions within the systems analysis.

18. Intensification of research efforts on influence of weather/climate on growth and development of plantation, spices, commercial, horticulture (fruits, flowers and orchid) and herbal crops which have received less attention in the past.

19. Promotion of studies on animal-climate and fisheries-climate interactions (including dairy animals, sheep/ goat, birds and poultry, inland fisheries) and influence of environment on the quality of output products. This is an unexplored area from the operational point of view (e.g., prediction of milk production), which is dependent on environmental conditions.

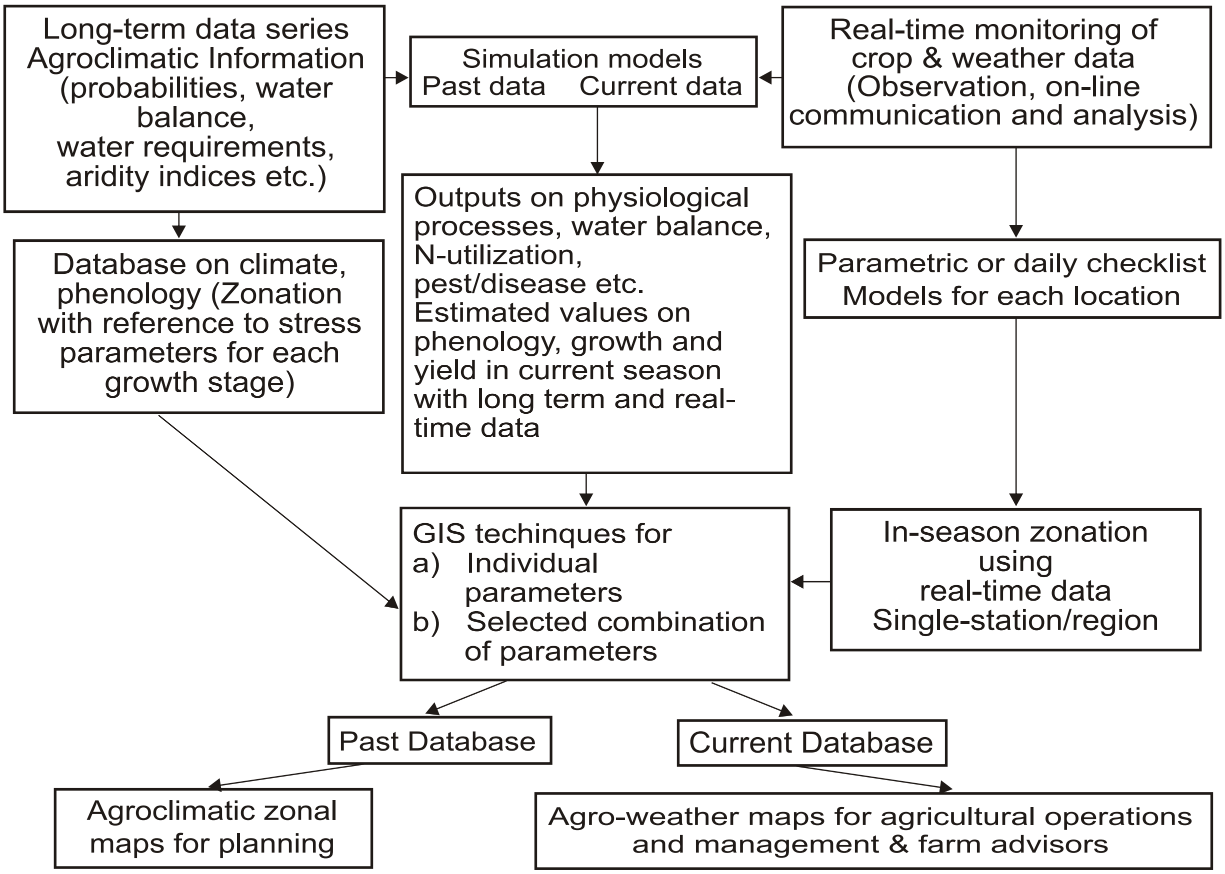
20. Weather effects (thermal and moisture regimes) with respect to maintenance of quality of agricultural products during storage, transport and marketing of the products, is another important area for investigation.

21. International collaboration and exchange programmes in interdisciplinary areas of Agrometeorology had been few and far between. These need support in all the three areas of teaching, research and extension related to agrometeorology / agroclimatology.

8.3 The Running Theme for the Next Two Decades:

The country is rich in long-term time-series data on climate (which is characterized by changing trends over the decades) and also long-term data on crop yields (with varied technological trends though, far less than those of the climate). Advanced computation capabilities, new approaches to analysis like simulation of crop –weather interactions using dynamic approach, sophisticated observation systems like satellites, remote sensing and automatic portable battery operated field measurement techniques, online communication facilities have become the tools for research in the recent decade and a half.

To take advantage of all these developments, in the coming two decades, it is our responsibility to proceed with a sense of direction in finding ways and means of integrating historical and current data, improved technological and measurement facilities, for making agrometeorological services for agricultural operations contributing to sustainability on the agricultural front. This approach is needed for ensuring food security, and for a better understanding of impact of climatic change and variation on crop growth and yield. These are depicted in the schematic chart below.



Since fortunately in the country, we already have a vital data and technological base, such an integrated approach needs to be supported by strengthening and streamlining of our efforts on several aspects bringing out necessary improvements in the weather forecasting and development of climate/weather-based crop planning and agricultural operations. Vision for "**Integrated and holistic approach in agrometeorology**" would be the theme and this document is an attempt to focus on the improvements needed and a vision, for the coming two decades with respect to various agrometeorological components constituting the agro-environmental cosmos.

8.4 Thrust Areas, Vision and Recommended Action

8.4.1 Resource Characterization of Production Systems

8.4.1.1 Agroclimatic Characterization—New Approach

Climatic characterization has extensively been done and now in the coming years "Agroclimatic Characterization" has to be the thrust. Innovative approach is needed. The following activities are suggested for achieving this.

- Urge for developing innovative approaches in analytical techniques should be promoted through appropriate motivation of the scientific community

- Phenological event-based agroclimatic characterization, rather than climatic summaries to receive priority

- Monsoon onset and withdrawal dates to be reference points for analysis in preference to calendar days as presently used

- Emphasis is to be given to studies on agrometeorological aspects rather than to agroclimatology, periodically updating the latter, once a decade

- Crop-weather response functions to be developed for understanding of short-period weather-induced effects on crop growth and development

Vision: *Sufficient information would be generated on agrometeorological aspects of land-vegetation processes as complementary to agroclimatic information. Innovative approaches find a significant place in research and analysis. Agroclimatic characterization is available for all the agroclimatic regions in the country.*

Need for introduction of "Agro-weather maps" using real time data

Development of location, time and crop cultivar specific regressions constitute the present crop-weather analysis. For economic and improved agricultural operations, cropped areas and areas covered by synoptic weather systems at any given time are to be synchronized. For this, crop information needs to be monitored on real time basis from several locations in a region and integrated with weather map, which could lead to the preparation of "Agro-weather maps" for formulation of agroadvisories. For this purpose:

- A systematic, organized and streamlined mechanism catering to both local and regional level weather-based agricultural operations has to be put into operation. Crop observation reporting sites should be maintained with communication facilities

- These data are to be immediately analyzed to prepare "Agro-Weather maps" by nodal agricultural research centers.

- This may need creating additional facilities at research centres by way of communication equipment, GIS (for mapping), software and a few scientific and technical personnel.

- To start with, this can be promoted as a pilot project at one or two SAUs, which have advanced facilities and gradually extended on permanent basis to other universities and ICAR institutes.

- "Agro-weather maps" on a regional scale could be the base for issue of agroadvisories, for drawing conclusions on cultivar performance, the crop yield pattern, effects of pest / disease distribution, flood and drought) in areas affected by adverse weather systems such as cyclone, heat and cold waves etc.

Vision: *All agricultural research centers (both State and ICAR) have necessary facilities to receive synoptic weather maps and prepare "Agro-weather maps" as a routine activity by the year 2010.*

Weather based agroadvisories are issued from AASUs based on these and also the medium range weather forecast all over the country by 2020.

8.4.1.2 Agrometeorological Information for Crops:

Agrometeorological information in respect of major crops lies reported in several research publications and unpublished thesis. The information contained therein for each of the crops remains to be brought together and compiled at one place in the form of technical reports. This basic information is vital for defining threshold values of weather elements affecting crop growth and development under field conditions.

This is a priority area for action since such definitions are the starting point for all further analysis aimed at development of weather-based agroadvisories. For achieving this objective, the recommendations are:

- Working groups may be constituted for major crop species for collecting agrometeorological information and defining the weather thresholds from published literature.

- This task can also be entrusted to working groups of senior/retired scientists located at places with good library facilities.

- Action may be taken by research institutes to conduct laboratory and field experiments with specific objective of filling up of gaps in information for evolving clear definition of weather thresholds for the different crop events.

- These activities may be supported through sanction of research projects for limited periods by DST/ICAR

Vision: *Agrometeorological information for several major crop species / production systems is available and preferably updated once in 10 years. Definition of threshold weather values are available in the form of manuals for all major crop species within the next ten years.*

Forms of Presentation and Types of Data Needed

Agrometeorologists should ensure that the information is relevant, accessible and presented with clarity. Long-term (for >30 years) and medium term averages (10-30years) are being described as 'normal', 'mean', or 'average'. Uniformity in data presentation can be ensured as follows:

- "Standard week" is the accepted time-unit for compilation of agromet data in India; preparation and presentation of data may continue to be on the standard week basis.

- 'Normal' values of weather elements as prescribed by WMO are to be worked out and differentiated from 'average' values

- For operational purposes, the format may be such that current values of weather elements are shown against the background of corresponding normal values based on long-term averages.

- Both on a real-time (current weather data) and on a climatological basis (long term normal values) for operational purposes, data presentation in map form would be preferable to individually depict, spatial spread and intensity of incidence of :

(a) tracks and aerial extent of passage of depressions, cyclones
(b) incidence and spread of drought
(c) heat and cold waves
(d) hazardous weather phenomena like frosts, heavy rains, floods, high winds etc
(e) Incidence / outbreak of a crop pest or disease.

Vision: *Agroclimatic normals with reference to crop growth phases for major crop species are available. Data would be presented both for individual stations and in a map format at regional level to depict spatial spread of stress effects on crops in relation to aberrant weather conditions. These are updated periodically say once in ten years.*

Uniformity and standardization in procedures and methodology

For purposes of comparative studies, information has to be presented at regional or national level. This implies that certain uniform procedures and methodology are to be followed by all concerned in data collection and analysis. Exposure of instruments, periods of observation, data sampling etc., all require to be specified and recorded during the experiment. Otherwise results become incomparable. Unfortunately, as evident from published reports, there is lack of uniformity in exposure of instruments, crop-weather observations and analysis in several cases.

In Agrometeorology, uniform standards and methodology have to be specified and followed by all concerned with respect to the following. This is only a minimum essential common requirement and not an exhaustive list:

- Field lay out for experimental crops
- Sampling techniques for each of the crop species
- Exposure of instruments in the crop environment
- Observational procedures
- Standard week to be followed as a unit for analysis
- Distinguishing between 'normal' and, ' average' as defined by WMO
- Terminology for phenology for the different crop species
- Agroclimatic characterization

To achieve such uniformity, it is recommended that

- Working groups may be organized with subject matter specialists and experienced scientists to bring out guidelines and manuals both for laboratory and field experiments.
- Since each crop species, as mentioned earlier, presents its own sampling problems for plant observations, it would be necessary to set up separate working groups.
- For coordinated projects, field layout, data collection, scrutiny and archival procedures for individual crop species should be standardized
- Project Directors and Project Coordinators for different crops of ICAR Coordinated schemes and research institutes may constitute working groups for evolving such

standard methodology and preparing manuals and guidelines for the respective crop species specialized by the institutes. Peer review and expert opinion may be obtained before finalization of such manuals. This work should receive priority and efforts should be made to complete this in about five years.

- At a later stage these can be made part of syllabi for practical work in teaching programs in agrometeorology and agroclimatology and other related sister disciplines through interdisciplinary programs.

Vision: *Manuals and guidelines detailing uniform and standard procedures for observation, sampling and analysis will be available in the next five years. Quality database is built up conforming to the prevailing standards and procedures.*

8.4.1.3 Characterization of Climate for Agriculture:

Agro-Climatic Characterization with reference to every rain gauge site in a state is essential. Rainfall statistics, water balance statistics etc., can be depicted as isoline maps. Data in different forms and aerial extents such as a watershed, drainage basin, mandal, taluk, district, or agroclimatic regions is in demand. Preparation of such base maps enable superposition of any other parameter-distribution map such as air temperature, cropping pattern, crop phenophase maps, animal husbandry / poultry population distribution, crop or milk yield, irrigation requirements, water requirements etc., for any specific and desired area, or targeted objective of study. The objective can be achieved as follows

- Using crop-weather threshold values, agroclimatic characterization may be done for every rain-gauge location in the country by the agromet units of SAUs.

- Base maps of agroclimatic characteristics without showing administrative boundaries but in manageable scales and section maps may be prepared indicating locations analyzed

- These should be ready in a form so that other parameter distribution maps could be superposed using GIS techniques

Vision: *Agro-climatic characterization is completed for every raingauge location and is available in mapped form with watershed as basis and/or as per user requirements. To be updated once in ten years.*

Quantification of Rainwater Availability for Water Harvesting

Whenever severe or disastrous drought occurrence takes place, one is reminded of harvesting of rainwater. However, this need not be an activity only for drought years, but should be a year-round process. This can lead to development of some sort of risk-avoidance mechanism for providing irrigation during rainless crop-growth periods. Such information would have practical application in agricultural operations.

This analysis can have several dimensions. Information may be generated to meet the following needs.

- Harvestable water on a climatic basis

- In-season determination of harvestable water from cropped areas

- Probable estimates of harvestable water for
  - (a) high, normal, low seasonal rainfall years separately,
  - (b) early, normal and late onset of monsoons, and
  - (c) early-onset, and late withdrawal of monsoons

- Development of dynamic simulation models for this purpose may be supported. Both in-season and historic data can be used in the models

Vision: *Information on harvestable rainfall amounts at weekly intervals, their spatial and temporal distribution is available for every agroclimatic region in the country. Dynamic simulation models are available for use with, both time series and real time data.*

Determination of Potential yields of crops in the rainfed regions based on weather and agroclimatic characterization.

'Potential crop yield' usually conveys the meaning that it would be the highest attainable yield under non-stressed conditions. Since moisture stress is a frequent phenomenon in the country, we can introduce the new concept of different potential yield levels in relation to 'wet', 'normal', and 'drought' kharif seasons in the dryland areas of the country.

The farmers' expectations could be more rational if such information on possibility of differences in potential yields for each region is made available. Such information is required for each of the major crop species grown in the dryland areas of the country for the different agroclimatic regions. The following steps are recommended.

- Reported potential yields from rainfed agronomic experiments conducted in the past under different management levels may be compiled

- Yield Estimates may be made for different moisture stress levels at different crop growth stages

- Yield Estimates for high, normal and deficient rainfall years may be generated using water balance procedures for each of the major rainfed crops

- The information may be presented in a map form for each agroclimatic region

Vision: *Potential crop yield maps would be available for each of the agroclimatic regions in the country in relation to 'wet', 'normal', and 'drought'* kharif *seasons in the next five years. These are updated every five or ten years in relation to improvements in Dryland technology.*

Adequacy and use of agrometeorological data

Database required for preparation of climatic statistical summaries currently available in the country, can be considered adequate. However, user requirement for agrometeorological data (studies on short period adverse weather and crop performance, and various transport processes) covers a vast range of information cutting across various spatial and temporal scales. Presently, this is inadequate. For remedying the situation the following recommendations are made:

- The crop experiments conducted in each season should be utilized for generating database on effects of short-period weather-induced response in crops

- Design of experiments and sampling should be such that over a period of not more than three to four seasons with respect to an experiment, sufficient data are generated and available as per standard analytical procedures prescribed

- Data from long-term agronomic experiments could be used by agroclimatologists to study long-term effects of climate variation on crop growth and yield

- Such experiments should receive priority and adequate project support

Vision: *More and more agrometeorological data measured over short periods within a crop season become available and response on crop performance under influence of short period weather induced effects are established. Guidelines for installation, maintenance, exposure and data collection are provided through manuals to achieve uniform standards.*

Building up of data on crop phenological events for agroclimatic analysis

The type of weather warning to be issued for adverse effects on crops depends on the stage of the crop growth. In the 'All India Coordinated Research Projects' for various crops, such information is collected only for date of sowing, anthesis and maturity. This is insufficient for agroclimatic analysis and simulation. This is a major lacuna to be filled up by initiating the following steps

- A standard terminology for identifying phenological events in crop growth for each crop species should be prescribed and defined unambiguously to remove subjectivity in observation to build up comparable and uniform database

- Immediate attention has to be paid for data collection on dates of phenological events for early, normal and late sowing times at a location for each of the major crop species from every experiment conducted by a research station

- In the farmer's fields regularly visited by agricultural experts and extension workers, it should be made mandatory to record data on phenological events at every visit

- After sufficient data are collected, the central agricultural research station should bring out a comprehensive distribution map of phenological events by the end of the crop season apart from periodic preparation of such maps within the season

- Agroclimatic region can be used as a base unit for such maps

- All the information should be communicated to the **'Data bank in Agrometeorology'** at CRIDA. This unit can bring out 'Phenology Atlas of India' for different crops after a five-year period of data collection and update it once in five years for taking care of climatic variation and climatic change effects.

- For handling such data, facilities at Data Bank in Agrometeorology should be strengthened suitably—human resources and equipment

Vision: *Large volume of data on crop phenology is available and archived for further analysis required for agricultural operations. Phenology atlases are available.*

8.4.1.4 Agroclimatic Zonation in India:

Studies on climatic classification in India were initiated in the country in the 1950's.

Information on agroclimatic and agroecological zones available and published in the country is considered sufficient. This exercise needs to be approached from a new angle, which will have utility both for planning cropping patterns and agricultural operations.

For example, it is possible to map out flowering time isolines for a crop like paddy all over the country in the kharif season or isolines of anthesis dates of wheat for wheat growing areas in the rabi season; flowering pattern in mango crop over the country super-posed by day length or thermal time accumulation etc., For each crop species such information can be included in zone maps. Both long term average data and current season data can be used for this purpose. This essential aspect has not received the attention it deserves.

- Agricultural research institutes should initiate such projects at the earliest possible opportunity.
- Project teams may be constituted in SAUs and National Agricultural Institutes for preparation of such zone maps.
- Scientists involved in preparation of weather-based agroadvisories may constitute such teams and prepare work plan for achieving the objective

Vision: Agro-climatic atlases depicting zonal distribution for major crops, depicting isolines of crop-weather parameters and dates of phenological events are available at district, state, national levels.

Information on Unsuitability of Crops in Agroclimatic Zonation Maps

Presently available agroclimatic or agroecological zone maps provide suggestions about suitability of the regions for particular crops. It would be more useful to delineate areas unsuitable for specified major crops. This information will help to prevent inappropriate use of land resources. Such a need arises since, even if the site is situated in a well-known drought core area, if electricity is available, farmers get tempted and resort to raising irrigated paddy crop in place of traditional drought tolerant crops, which ultimately leads to over-exploitation of ground water source and also becoming uneconomic. The suggested types of delineation may provide a guideline to farmers. As and when irrigation facilities are extended, these are to be redrafted.

Vision: Future agroclimatic zone maps indicate zones unsuitable with respect to major crops, and updated every five years.

Agroclimatic Zoning of Hilly Areas:

Agrometeorological observatory network in the plains of the country is sufficiently adequate. However, network needs of the hilly and island regions warrant a review. Differences in aspect and slope of mountainous spots play an important role in receipt of solar radiation, evaporation rates, rainfall amount and distribution.

Measurements in the hilly region become spot-specific depending on the location, where the observer is placed. Climatic characterization of hilly regions is a tricky but important problem. A few meteorological and agromet observatories are functioning in these regions but in the light of above points raised, these need a review from the point of view of operational agriculture and development of weather based agroadvisories for the hilly regions. This is a priority area that needs attention. The following action is suggested.

- A working group may be formed for making specific report on the status and future agromet observatory network needs of the hilly areas.

- Personnel from the ICAR institutes in hilly areas, IMD, DST, NCMRWF, SAU in hilly areas, may be the members of this working group with associate members from NIH, Survey of India, Indian Institute of Forestry, SAC and Defense Organization for national security considerations.

- This group can also examine the network and facilities needed for island areas.

Action may be taken to expand Agromet observatory network in the hilly regions and island areas as per recommendations of the working group

Vision: *Agromet observatories are established in crop-grown or vegetated pockets of hilly regions and climatic / agroclimatic characterization of these is available.*

8.4.2 Research and Development

8.4.2.1 Functional Relationships for Crop-Weather Interactions:

Generation of response functions between production and protection related biological responses and weather through interdisciplinary approach

Qualitative or empirical information acquired by local expertise often remains with the scientist or extension workers concerned, or passed on from one to the other orally. It is yet to be compiled in a written format and supplemented with quantitative determinations.

The immediate need is for quantitative determination of crop response functions to imposition of short-period weather-induced stresses of various types (moisture, heat, cold, pest/ disease etc.,) i.e., to determine rates of processes underlying crop performance. Project support is recommended for this purpose as follows.

- To encourage senior scientists (both serving and retired) to record in writing their personal field experiences and hunches concerning weather effects on crop growth or such events considered peculiar or significant by them for publication as local bulletins. These can be descriptive or qualitative in nature

- To provide round the clock data recording facilities from field plots using portable instruments and battery operated data loggers for agrometeorological research

- To effectively utilize dates of sowing experiments for such short period measurements *in situ* which may necessitate ready availability of multiple sets of sensors with automatic recording facilities

- Such projects should be encouraged as 'Institute programs' at the major research institutes, with participation of permanent scientific personnel along with post-graduate candidates, or as fellowship programs

Vision: *Information on rates of processes in crop-soil-atmosphere interactions are generated and are available. Several types of crop response functions with climate are utilized in crop-weather dynamic simulation models and EXPERT systems for day to day agroadvisories for agricultural operations.*

Pre-release agronomic trials and development of crop-weather response functions:

Plant breeders, agronomists, entomologists and plant pathologists conduct pre-release trials simultaneously for a few seasons before the final release of the new crop cultivars. Demonstration experiments are also laid out.

Establishment of crop-weather relations should preferably coincide with the pre-release trial period of new cultivars. This way, these studies can keep pace with the findings of sister disciplines like plant breeding, agronomy, entomology and plant pathology who conduct simultaneous trials. Emphasis by agrometeorologists during the pre-release trials or demonstration experiments should be on establishing crop-weather responses with respect to short-period weather-induced effects on crop growth and yield.

Vision: *Pre-release cultivar experiments are used for developing crop-weather response functions. Functional relationships between short-period weather-induced aberrations and impact on crop growth are established in interdisciplinary mode with plant breeders, agronomists, pathologists and entomologists.*

8.4.2.2 Micrometeorology: Microclimate and Modification

Micrometeorology deals with environmental conditions within and around the canopy. It is a result of crop-environment reaction and influenced by meso- and macro scale weather on occasions. Momentum, heat, moisture, CO_2 transfer processes, pest/disease incidence and growth, effective dissemination of pesticide sprays are all part of the microclimate system. Effect of adverse weather can also be ameliorated through modification of microclimate both in crops and animals. This has been the least studied aspect in the country. At agricultural research stations, establishment of micrometeorological towers would be a multi-purpose utility both for research and agricultural operations. Thrust activities recommended in this field are as follows:

- Establishment of micrometeorological towers with multiple sensors at as many agricultural research stations as feasible and maintainable. Case by case examination of requirements and utilization prospects is needed.
- Integrated Land Ecosystem Atmospheric Process Studies (ILEAPS) type of long-term observational campaigns in different agroclimatic zones needs to be supported. These locations may be brought under the International Geosphere Biosphere Programme (IGBP) network.
- Boundary layer characterization through generation of data on wind, moisture and temperature profiles in and above crop canopies under clear, cloudy and over cast sky conditions at different growth stages.
- Energy balance studies of crop canopies under different soil/crop cover conditions with respect to mono and inter cropping systems.
- Assessment of advective heat transfer to crop surfaces from surroundings in different seasons at different growth stages.
- Studies on dissemination pattern of chemical sprays in relation to weather profiles in and above the canopy in the boundary layer.

- Studies on effect of modification of microclimate on soil moisture, thermal regimes and energy balance in crop canopies.

- Research in air pollution effects on crop canopies.

- Determining the spray schedules of insecticide, pesticide, fungicide etc., using microclimate profiles on wind and temperature.

- Promote and encourage indigenous fabrication, manufacture and calibration of sensors and recording equipment for micrometeorological measurement.

Vision: *Micrometeorology and effects of microclimate modification are fully understood and used for amelioration of crop growth environment under heat, moisture and other weather induced stresses, and for decisions on chemical spray schedules. ILEAPS would be a significant activity enabling improvement of medium range weather forecast capabilities for framing more realistic weather based agroadvisories.*

Relationship between Macro-, Meso- and Microclimates in the open and Microclimate of crop Canopies:

The crop as it grows in height and spread, develops its own microclimate as influenced by macro weather systems. This is not always measurable in every cropped field. On the other hand, information on macroclimate is readily available from the observatory network. The macro weather data has to be interpreted in terms of micro-climatic conditions obtaining in the cropped fields at any desired point of time. Such relations are unavailable in the country and are yet to be developed. It can be taken up in a project mode since it may involve generation of large database even at one single location on microclimate in cropped fields. The following investigations are recommended.

- Establishment of automatic recording microclimatic towers in cropped fields (major crops of the region) at nodal research centers.

- Correlation of macro and micro weather data to establish seasonal coefficients for the different crop growth phases

- Verification of the coefficients for a period of at least three seasons for different crop species at different growth stages

Vision: *Macro-micro climate relations are available for various crop-environment scenarios and also under adverse weather conditions influencing crop-animal productivity. These are routinely used in formulating weather-based agroadvisories.*

Hourly Data:

Recent advances in Agrometeorology have brought to the fore the need for hourly values of weather parameters. Hourly data are also needed as data input for dynamic simulation modeling, studies on micrometeorology of crops, short period weather influence on crops, sequential occurrence of weather elements at critical threshold levels etc.

For several years, IMD had been maintaining self-recording instruments for temperature, wind, humidity and radiation. Data have been published only for very few years. Since the 1990s some automatic weather stations (AWS) that provide hourly data have been installed in agricultural research institutes and universities. These presently cater to the needs of individual research projects. The data do not seem to be archived on any systematic basis. The steps that are needed are:

- Retrieval and archival of all available hourly data on surface weather elements observed through maintenance of self-recording instruments available with the India Meteorological Department

- Publication of this data (or entered on CD ROMs). Data bank in Agrometeorology functioning at CRIDA can cooperate in this process

- At locations where AWS are already functioning, the hourly data from these may be retrieved and archived at the Data bank in Agrometeorology at CRIDA

- Creation of special cells at IMD/CRIDA for clearing arrears in data scrutiny, analysis and publication in a time-bound project mode

- Augmentation of AWS after thorough review of the present set up of these stations in the country

- Streamlining observation, scrutiny, archival of hourly weather data and their publication

Vision: *Hourly data are available as a routine both from manual graphical records and automatic weather stations in the country.*

8.4.2.3 Crop-Weather Simulation Models Using Dynamic Approach:

Development of User-targeted Operational Crop-weather models with real-time crop-weather data as input

There are diversified users of agrometeorological information and weather-based advisories, both on long term and short-term basis. Even a single user has several specific queries for which solutions are to be given in the form of agroadvisories in the growing season. Such advisories for agricultural operations need more quantitative basis, eliminating subjectivity to the extent possible. Development of "**user requirement targeted models"** is suggested as a priority area for this purpose. This is of specific interest and relevance to improvement of agro advisories being issued under the NCMRWF and ICAR, IMD agromet advisory programme currently in operation. To achieve this, the following recommendations are made.

- Sub-routine programs of the comprehensive "Systems models" (crop-weather simulation models using dynamic approach) should be profitably utilized with real time data.

- Sub-routines on water balance, root growth, pest/ disease model, run-off model etc. and several such components should be taken as independent entities, calibrated and validated for local conditions.

- Keeping in view various user requirements simulation models may be developed and validated for every location at nodal research centers with respect to specific user requirement for major crops grown in the region.

- Development of such user requirement targeted models may be supported in the research project mode.

Vision: *User targeted models for use with real time data are available for operational purposes and are routinely utilized in any current season. Periodic updating is also done where necessary.*

Simulation Models as Forecasting Tools within a Crop Growing Season

Simulation models can be run in any current season from day one of crop germination with real time data as input upto any current date, and with normal crop-weather data for the remaining growth period. Various possible scenarios can also be introduced for the latter period of growth to obtain estimates under different expected scenarios well before harvest of crops. Obviously, as the current data input component increases, the period of normal data input gradually decreases. This type of exercise is yet to be introduced in the realm of simulation modeling in the country.

The following activities are suggested

- For any simulation model, indigenously developed or that adopted from abroad, invariably, sensitivity analysis, calibration and validation should follow in that order.
- Model should be run using both current data and normal/expected weather variations and growth / production estimates given as agroadvisories.
- Models should be run with reference to crops grown in research farms (control conditions) as also those grown in farmers' fields, which have different management levels in any current season. Correction factors if any, are to be worked out.
- Different models are employed for different crop species and more than one group may be involved in such activity at the same institution and these may not be considered as superfluous.
- Indigenous development of crop-weather models at identified lead centers of ICAR should be encouraged through project mode.
- Training of agricultural scientists in computer programming and software development is considered essential for success in this activity. These activities can be considered as priority areas in the institutions where facilities exist and may be generously supported by sponsoring institutions.

Vision: *By 2010, most of scientists are active software developers and operational models are developed indigenously with weather elements as major input. By 2020, model application in current season with real time and normal data inputs is a routine activity of the agrometeorologists for formulation of weather based farm advisories.*

Development of EXPERT Systems:

As a follow up of the above information, operational models and EXPERT SYSTEMS can be developed for use with real time data, for each of the major crops in the different agroclimatic zones of the country or even for smaller geographical units. These are practically non-existing in the country today in the field of agrometeorology. There is immense scope for expert system software in application of agrometeorology for agricultural operations. The following activities are suggested for remedying the situation.

- To start with, such EXPERT systems may be developed to prepare advisories on "critical weather and sowing schedules, irrigation and fertilizer application, plant protection measures, crop /fruit harvest schedules" etc.

- Scientists at the SAUs and national institutes, CRIDA, NCMRWF research groups, emeritus scientists can be involved in this exercise aided by short-term research projects

Vision: *EXPERT SYSTEM MODELS and SOFTWARE are available as solutions for several queries on agrometeorological aspects in different weather situations for agricultural operations. Extensive use is also envisaged.*

8.4.2.4 Biometeorological Aspects: Livestock, Poultry and Fisheries

Animal – Climate Relations:

Output products from animals including poultry, goats, sheep, exotic birds, animal growth and diseases affecting them, their living environments are known to be governed by weather condition. Development of quantitative climate-animal relationships and efficient utilization of daily weather data for monitoring the various aspects, which at present can be said to be non-existent, is a research priority.

This thrust area on quantifying climate-animal relations, which, to start with is exploratory in nature, requires strong support from DST/ICAR in improving the existing infrastructure. Envisaged findings would have economic importance, as some of the products are exportable commodities. Research thrusts could be on the following: (Covers all species of live-stock, dairy animals, birds, goats, sheep, poultry etc., though not specifically mentioned).

- Homo-climate zoning for different animals and livestock, poultry etc.

- Heat balance of animals (a) in relation to their housing structures (b) in different seasons (c) age of the animal (d) productivity

- Heat transfer from surroundings and its effect on (a) quality of nutrition needed (b) on yield of products (c) physiological processes

- Partitioning rates of shifts in fluid compartments during heat stress

- Energy balance of animal housing structures in different seasons

- Effect of temperature on survival, egg and meat products in poultry

- Climate-nutrition relations in draft animals.

- Climatic conditions and wool fineness at different altitudes

- Lag period of response to (a) imposition of stress events such as heat, drought, cold etc. (b) time duration of recovery to normal conditions (c) yield pattern from time of imposition of stress to return to normal conditions. These have to be studied for animals of different ages.

- Forecasting seasonal outbreak of bacterial/viral diseases in animals and poultry.

- Relationship between observations under controlled and natural environment
- Modeling of animal-climate relations and yield prediction using dynamic simulation techniques
- Application of results and relationships already developed for predictive purposes at field level—weather based agroadvisories
- Creation of infrastructure like climate chambers, equipment for energy balance studies
- Framing of composite syllabi at PG level on animal-climate relations including pest / disease development
- A databank to be developed on animal-climate effects and ameliorative measures

Vision: *Models are available for routine use with real time weather data to predict animal health / productivity / yield from functional relationships between animal – weather interactions. Items such as milk yield, poultry products, disease incidence etc., are predicted on a routine basis for all agroclimatic regions in the country.*

Fisheries – Ocean climate relations

Catch of fish is known to be related to ocean climate, upwelling and sinking processes which are influenced by seasonal weather / climatic systems. This is one thrust area that requires attention by associating the 'Central Fisheries Research Institutes' with National centers of research in oceanography or ocean climate. This has relevance to ICRP, where research projects are in operation for study of ocean climate and monsoon activities. Research programs are to be initiated in the following areas:

- Effect of synoptic weather systems on seasonal variation in multiplication and catch of fish
- Effect of weather and climatic variations on growth and multiplication of fish with special reference to changes in sea surface temperature
- Separate programs to be initiated for inland and marine fisheries

Vision: *Climate-fish growth and multiplication relations are fully understood and models are available for preparation of weather-based advisories.*

8.4.2.5 Agrometeorology and Remote Sensing:

Remote sensing for estimation of crop acreage and crop cover for major crops at periodic intervals

Satellite imageries are providing information on crop parameters through determination of various vegetation indices. These studies will have to be intensified. Simultaneously, it is essential that from ground truth sampling of data from various agroclimatic zones, crop cover and yield estimation is made a routine activity of nodal agricultural centers. Regional level medium range weather forecasts with reasonable accuracy are likely to be available in the coming decade and it is imperative to strengthen research on regional level effects of disastrous weather events on crop conditions.

- Ground truth sampling activity should become a routine at nodal agricultural research centers. Necessary facilities by way of personnel and equipment needs to be created

- Research on quantitative determination of likely production losses in a given season as affected by major adverse weather systems and related stress events need to be initiated and strengthened

- Management strategies for various scenarios and action plans to be evolved through sustained interaction among Agromet Centers, State Meteorological Centers, State Directorates of Agriculture and Space Application Center in the country

Vision: *Remote sensing imageries of crop cover of major crops are available as a routine at regional level with information on acreage and yield estimates. These are supplemented by ground based mapping of effects of disastrous and aberrant weather events on different crop species at regional level. Weather based advisories are prepared based on the remote sensing imagery, crop condition maps and medium range weather forecasts at regional level.*

Remote sensing estimation of surface soil moisture through microwave techniques

Satellites using microwave bandwidths are in operation now. These are likely to be increased in number for estimation of soil moisture status under different land use patterns, on a countrywide scale. Being a promising technique, research thrust in agrometeorology should be laid on development of algorithms between surface moisture conditions with that in the different soil profile layers for the different cropping systems. To meet the needs in agrometeorology, the following activities are identified.

- Soil moisture characterization using water balance techniques for different agroclimatic regions. Simulation models can be used after validation.

- Development of algorithms between surface moisture with soil moisture profile under different cropping systems at different growth stages

- Regional level soil moisture monitoring and mapping at weekly intervals in a current season particularly with reference to rainfed crops

Vision: *Surface moisture maps using microwave remote sensing techniques for the country would be routinely available for use in agricultural operations. Algorithms between surface moisture and profile layer soil moisture content are in use for determination of irrigation scheduling, amounts at regional level using real time crop-weather data.*

Remote sensing techniques in locating incidence, development and spread of drought

Crop spectral indices provide an indication of incidence, development and spread of continental drought. It would be possible in course of time, to map out intensity and spread of drought over different parts of the country through satellite imageries as a routine, and the aerial extent to which individual crop species are affected in any cropping season. For effective utilization of the satellite imageries for agricultural operations, from agrometeorological angle, the following lines of work are suggested for the coming two decades.

- Surface soil moisture maps through microwave remote sensing imageries at periodic intervals during crop growth season should be correlated with drought

/ aridity indices and ground truth information on drought occurrence. These could form the base for advising mid-term corrections or alternative cropping pattern based on known crop-weather characteristics.

- Research thrust in agrometeorology should be on development of crop contingency plans based on crop-weather-soil drought intensity patterns expected during the cropping season. Dynamic crop–weather simulation models can be extensively employed in such research.

- Efforts should be made to develop an 'early warning system for drought occurrence' on a regional scale in a current season based on satellite and ground truth information. Work could be initiated in all agroclimatic regions for major rainfed crops. To start with, these may be supported as pilot projects at National Agricultural Institutes and Agricultural Universities.

Vision: *Remote sensing imagery of crops and cropped zones affected by drought at important phenol-phases of crops are issued as a routine at periodic intervals. These are utilized with crop contingency plans / management strategies for drought conditions based on real time weather and crop information.*

Remote sensing techniques for locating flooded zones and their recession

Periodical remote sensing imageries can be utilized to demarcate flooded zones caused by heavy rainfall over cropped fields and their recession time. These are helpful in crop planning (choice of species, cultivars, provision of drainage outlets and other agricultural operations) involving agrometeorological considerations. Steps suggested are:

- Development of crop contingency plans for flooded zones based on crop-soil-weather characteristics and the seasons in which these floods occur.

- Determination of time period required for flood recession for different rainfall accumulations in relation to evaporation, drainage outlets and soil moisture holding capacity is a priority area for research. This has not received much attention earlier.

- Mid-term corrections may also be possible and contingency plans of agricultural operation should include this aspect.

- Research on crop contingency planning based on crop-soil-weather characteristics needs to be promoted in project mode

Vision: *Remote sensing imageries for flooded zone are periodically available. Crop contingency plans are included in weather-based agroadvisories and put in operation without loss of time whenever widespread flooding of cropped areas is observed through remote sensing techniques.*

Remote sensing techniques in locating incidence, development and spread of major crop pests and diseases at periodic intervals

In the near future there is very likelihood that satellite imageries are routinely issued at periodical intervals indicating the cropped zones affected by pests and diseases. Chemical spray schedules prepared on the basis of weather conditions around the crop environment can lead to minimal use of chemicals by appropriate choice of height of application in relation to temperature inversions and wind speed characteristics. Research activity required for this is listed below.

- Climatology of temperature inversion layers close to the ground and their persistence with time to be studied.
- Development of models to provide advance information on 'Fog' incidence and duration related to synoptic systems for different agroclimatic regions.
- In-season monitoring of temperature inversions close to the ground and their structure around and within the cropped fields

Vision: *Micro and macro agroclimatic characterization is available in relation to determination of time and height of ground based and aerial based sprays for pest / disease affected cropped zones. This characterization is utilized with real time weather, crop pest/disease, conditions for agricultural operations as a routine assisted by remote sensing imagery.*

8.4.2.6 Climatic Change, Variations and its Impact on Agriculture:

Monitoring of Effects of Climatic Variations / Change and Their Impact on Yield; Prediction of Crop Productivity in Relation to Shifts in Climatic Belts

Climatic change and variations, their effect on global warming, are under intensive study by meteorologists. However, research projects specifically devoted to study impact of climatic change or variation, effect of latitudinal shift in climatic belts and their projected influence on cropping pattern and quantitative changes that may be brought out in yield potential are meager. Research activity should cover the following:

- Preparation of agroclimatic zone-wise atlases depicting impact of climate change / variability and rainfall, temperature trends in relation to crop productivity
- Expected shifts in rainfall and cropping zones with respect to climate change scenarios
- Impact of climate change and variation on agricultural production systems viz., cropping systems, livestock, pest / diseases and soils
- Spatial and time variations of the vulnerability of different crop species to climatic change
- Impact of climate variability on agriculture in relation to projected variations in moisture and thermal regimes, soil carbon storage and land use pattern
- Extent of crop adaptation to climate variation over a time period
- Separation of short-term effects due to 'climatic variability', from the long-term impact of 'climatic change', which need different management strategies and solutions.
- Quantification of green house gas (GHG) emission levels from agricultural sources / practices, and their dissemination pattern, both in the vertical and in the horizontal
- Impact studies on different crop management levels with regard to fertilizer application, carbon sequestration, soil and water management in realization of yield potentials for both *kharif* and *rabi* season crops
- Impact of intensive agriculture on local climates with respect to environmental quality.

- Development of strategies for crop planning in the light of projected changes. This activity will have to continue receiving attention in the coming two decades and beyond.

Vision: *Impact of short period climatic variations and long-term climatic change on different production systems is fully understood in quantitative terms at various spatial scales and different scenarios. Ready reckoners or simulation programs are available for assessing the impact in any current year.*

8.4.2.7 Forest and Agro-forestry Meteorology

Forest Agrometeorology:

Forest areas have their own microclimate and radiation penetration is one of the most important parameters that has a bearing on moisture distribution below the canopy. Denudation of forests changes climate at a meso-scale in the neighbouring areas also. This is an important area for agrometeorological studies. Forest fire is another significant area that needs attention, since there is increasing demand for prediction of favorable conditions for forest fire incidence, duration and favourable weather for ameliorative action.

Meteorology of the Agro-forestry:

Since the past decade, attention has been paid to expansion of agro-forestry for semidry areas and with reference to reduction in air pollution close to the urban areas. Also, "crop cafeteria"— crops of several heights and spread grown in areas like Kerala state is a system for which no agrometeorological studies have been specifically made. In view of the current demand and plans in the future for expansion of agro-forestry, it is recommended that:

- Efforts should be made to understand the agro-forestry and crop-cafeteria as whole system and crop-weather relations established with respect to radiation receipt, energy balance, moisture, pest/disease activity, animal habitat and other relevant parameters

- Results from such studies are to be integrated for the agro-forestry system as a whole in a region (a) for predicting forest fire outbreak, (b) for estimating seasonal variation of air pollution in the neighbourhood and (c) other beneficial effects of agro-forestry system

- Study effect of denudation of forest area on the micro and meso-climate and cropping system in the region is an important problem for research

- Modification in watershed characteristics due to agro-forestry.

- Impact of climatic change on timber production.

- Multiple sensors and other logistic support may be provided through project mode being an exploratory area in agromet studies, this area of research needs full support

Vision: *Forest eco-environment is better understood and used in further planning of expansion of forest and agro-forestry systems. Advance indications of forest fire occurrence, effects of denudation on micro/macro climate are provided for ameliorative action. Effects on possible climatic change on local and regional weather in the long run are assessed.*

8.4.3 Agrometeorological Services to Agriculture

8.4.3.1 Crop Yield Forecasting

The significance of crop yield forecasting at national, regional or village level is well understood and needs no repetition. Long range forecast or a weather forecast at least one year in advance would help in crop planning and yield forecast assessment. Even a seasonal forecast would be of great help. However, since efforts in this direction are yet to yield a reliable result, short and medium range weather forecasts can be utilized for yield assessment. Dynamic crop-weather simulations should be used for this purpose through in-season use of the models with real time data from day one of crop growth. Both current and normal weather data will be the input and as crop growth progresses, period of normal data gets decreased. This way, in-season estimates of yield can be obtained. For agrometeorologists, till seasonal weather forecasts are available, this is an option, which should be seriously practiced. However, models for each of the major crops will have to be applied. The following activities are recommended.

- Dedicated groups of scientists working at an institution with advance facilities may be identified and assigned this work by the agricultural institutions.
- Through crop monitoring, simulation models may be run in real time of crop growth, and yield estimates for different weather scenarios determined periodically for an agroclimatic region as a unit.
- Intensive training in model application may be organized for selected groups for each of the major crops to start with, the above activities may be supported as pilot projects at two or three agromet units of the Agricultural Institutions for two or three major crops of the region
- Yield forecasting through use of crop-weather simulation models may be gradually extended in the coming years in the light of experience gained through pilot projects
- Necessary logistic support (personnel, equipment, allowances), intensive training in developing /understanding and modifying source codes of models may be provided.
- In the long run, as monthly and seasonal weather forecasts are forthcoming, they can be utilized for crop planning in accordance with estimated yield targets and farm resources.

Vision: *Agricultural product-yield forecasts through use of dynamic simulation models become a routine activity at several institutions. Integration of these estimates are made for each crop species within and beyond contiguous agroclimatic regions resulting in a regional level yield forecast.*

8.4.3.2 Weather-based Agroadvisory Services

Agrometeorological Advisory Services

Major objective of these advisories is to provide information based on the expected weather, regarding farm operations, 2 to 10 days in advance. Both short range and medium range weather forecasts are utilized for this purpose. Presently (year 2006), 107 of the 127 proposed AAS Units are in operation in the different agroclimatic zones all over the country under the NCMRWF. User requirements are for a seasonal weather forecast along with medium range forecasts issued now.

For several operational purposes in agriculture, related to insect migration or air pollen, availability of synoptic charts (with one or two upper air level wind or contour charts) at AAS locations are considered as an essential requirement. With vastly improved communication facilities, this should not pose a problem. This arrangement is expected to improve the present weather based agroadvisory services. The following steps are recommended:

- Modalities are to be worked out between the NCMRWF, CRIDA, State/regional centers of IMD, and the AASUs for communication of synoptic and upper level charts as fast as possible in the day

- Expansion of AASUs to all 127 locations to complete the network along with the required manpower and instrumentation

- Strengthening of research efforts to increase forecast period initially from the present 4-days to fortnightly periods ultimately leading to issue of monthly or seasonal weather forecasts, which are user requirement for agricultural operations.

- Creation, up-date and maintenance of a website for ready access to various weather forecast products and advisories.

- Prepare audio-visual aids on agroadvisories towards popularizing among the rural population on the meteorological applications in agricultural production systems.

- Research needs are to be directed towards increasing the resolution of the weather forecast models and issue of monthly and seasonal weather forecasts for agriculture

- Promote support-research in crop-weather modeling and EXPERT system for improving weather-based agroadvisories.

- Improve infrastructure and manpower at NCMRWF, CRIDA and AAS Units commensurate with the proposed expansion of activities

In-season and Post-season Monitoring of Crop-weather Situations

Crop-weather diagrams:

For monitoring crop growth in any current season, for each crop species, preparation of crop weather diagrams or calendars depicting current events of crop growth is advisable. In these, against each of the growth phases, the type of weather phenomenon for which weather warnings are to be issued should be indicated. This is a practice that can be followed at several agrometeorological centres in the country as a routine.

Vision: *Crop-weather diagrams are available for each season / year and crop weather calendars are prepared in pictorial form by all concerned as a routine. Such information is published as a routine by the institutions engaged in crop-weather interaction studies.*

Post season monitoring and review of crop situation in relation to weather

Weather-based advisories provide an advance warning of impending weather, both favorable and unfavorable. The effects of the actually realized weather on crops must be analyzed which can provide guidelines on (a) where and in what weather situations did we succeed by forewarning (b) in what weather situations did we fail and could this have been avoided? (c) What remedial action can be taken to minimize such failures. The review in the post-cropping season should be done as a routine ***at the end of every cropping season*** for each of the crop species individually, before one forgets the realized impact.

- Monitoring cells may be created at NCMRWF and Institutes of ICAR for such review.

Vision: Post-season verification of weather-based agroadvisories and corrective action would have become a routine practice.

8.4.3.3 Early Warning System for Agricultural Drought

Several significant efforts have been made in the past on the front of drought research. Agroclimatic characterization of drought for different states in the country have been made. But most of these are related to meteorological drought. Since drought affects, not only crop growth and yield, physiological functions of animals, but also water availability for irrigation, pastures and fodder for animals, research should be aimed at covering these aspects. The areas for investigation with reference to *agricultural drought* are given below:

- Results of past studies should be compiled to show spatial distribution maps for agroclimatic regions with individual reference to major crop species and reviewed

- Pheno-phase characterization of effect of drought on each crop species in the different agroclimatic zones both at local and regional level.

- Developing specific drought criteria for different crop species is a priority research area. Agrometeorologists, agronomists, plant physiologists and plant breeders could constitute a team for this purpose.

- Once the criteria are developed, EXPERT Systems software should be evolved for use with historical or current database.

- Specific efforts should be made for identifying current season drought incidence and severity, separately for each of the crop species since some growth phases and crop species are drought resistant; similarly, for animals of different ages.

- More attention is needed to predict severe and disastrous droughts (with reference to crops, animals, irrigation requirements) by concentrating investigations on this aspect. Both local and regional space level and time periods are involved in this.

- Regional level crop monitoring at least at weekly intervals, separately for each species, is necessary with respect to physiological symptoms, crop-air temperature differences and soil moisture status.

- Drought warning advisories for agricultural operations, crop-wise, region wise, using medium range weather forecasts, synoptic systems and satellite images both in space and time scales should be developed. An integrated view should be adopted.

- Infrared thermometry may be employed for drought surveys on a meso-scale.

- Steps may be taken to issue mid-season crop yield forecasts for different intensities of drought (for each crop species) and scenarios (irrigated and rainfed situations and other significant factors) using simulation models.

- Agricultural drought monitoring cells may be created at nodal research centers for the above purpose. Initially, known drought prone areas may receive preference for opening these cells and gradually extended to other regions.

Vision: *Weather based advisories on agricultural drought are available as a routine in a current season for each major crop species with reference to different phenophases, region-wise, based on current weather, synoptic conditions, satellite imageries and medium range weather forecasts. Early warning and EXPERT Systems become available for all regions in the country.*

Crop Contingency Plans and Schedules—Review after every five years

Several Agricultural Universities, State Directorates of Agriculture, CRIDA had been evolving crop contingency plans and suggesting ameliorative measures for meeting impact of aberrant weather situations on crop performance. There seems to be a lack of systematic approach to this activity. For the results from such an exercise to be effective, the following recommendations are made.

- A comprehensive region-wise review may be undertaken every year by the National Research Centres and ICAR Institutes, and updating once in five years.
- Wide publicity to such contingency plans may be given in advance instead of waiting for a calamity to occur. Preparation of manuals in advance would be useful for this purpose.
- Alternative strategies may be worked out keeping in view the feasibility of application of such contingency plans in practice, at affordable cost. This is an interdisciplinary activity but centered on weather situations.

Vision: *Crop contingency plans and schedules for anticipated weather aberrations are readily available for all agroclimatic regions and revised / updated once in five years and given wide publicity which may be in the form of manuals or guidelines (in the form of books or CD ROM) available to the farming community.*

8.4.3.4 Weather-based Forewarning System for Crop Pest/Disease Outbreak

Pest / Disease – Climate relationships:

Development of weather-based forewarning systems is the need of the hour in limiting possible excessive usage of insecticides, pesticides and fungicides. Weather based prediction models developed till this day have been in the form of regressions. These succeed in one season and fail in another season. Quantitative relations developed to express climate-pest/disease organism interactions are very few. These are needed, since pest/ disease incidence and development into an epidemic has to be synchronized with the dynamic nature of weather variations. Research thrust should take this direction. The following steps are recommended.

- Development of standard and comprehensive format(s) for data collection is a prerequisite.
- A minimum data set is to be identified with freedom for optional/additional data collection.

- Threshold values of weather parameters for each individual phase of growth cycle of the pest / disease organism are to be defined.

- Filling up gaps in knowledge on pest/disease – weather relations in different growth cycles through laboratory and field studies and identification of threshold values.

- Organize in-season monitoring of pest disease status in cropped fields through network program involving different AICRPs of ICAR

- Organize measurement of leaf wetness duration at as many locations as possible.

- Development of prediction models using dynamic simulation techniques with real time crop-weather data and their validation with teams comprising of plant protection scientists and agrometeorologists.

- Develop strategies for integrated pest management based on weather.

Vision: *Crop-weather thresholds for every growth cycle phase of pest / disease are readily available in quantitative terms. Based on these threshold values, early warning systems are developed for conceivable weather situations and used with real time data for in-season agricultural operations, leading to optimum / minimum use of pesticides / insecticides.*

Use of synoptic surface and upper air charts for pest/disease control operations

Measurement of microclimate in the cropped fields, use of surface and upper air synoptic charts upto 2-3 km are needed. Except in the case of locust studies and brown rust on wheat, such information had not been generated in the past. This is a priority area for development of successful models on early warning systems specific to certain insects and species that are carried by the air stream or those whose movement is influenced by low-level cyclonic and anticyclone circulation. The following action is recommended.

- Determine threshold values of weather and population of organisms

- Identify temperature inversion heights and duration in cropped fields at different growth stages

- Characterize periods of combination of inversion, dew/fog, and wind in the growth season

- Prepare guidelines for spray schedules as recommended by C Ag M of WMO.

- Create facilities for receiving synoptic weather and upper air charts at nodal agricultural research centers

Vision: *Information on microclimate and synoptic charts are utilized as a routine for determining control measures in plant protection.*

8.4.4 Agrometeorological Research and Instrumentation

8.4.4.1 Instrumentation for agrometeorology

Development and Fabrication of instruments

For almost all equipment with spot reading or automatic recording facilities used in agrometeorological work, we are depending on imports even today. As stated earlier, urgent need is for encouraging development of various types of sensors, their testing, and calibration. Waiting for sensor imports results in loss of data, discontinuity in observations and waiting time, not to speak of freight and insurance costs sometime exceeding the cost of the sensor itself. This is one of the most important priority areas that can be taken up since immense trained manpower in engineering, technology, and manufacturing capabilities are available within the country. Steps suggested are:

- Projects are to be taken up to achieve self-sufficiency in manufacture of sensors used in agrometeorological research within the country.

- Almost all electrical and electronic equipment to measure temperature, wind, radiation, leaf wetness, photosynthesis, light intensity, florescence, transpiration, infrared sensors; automatic recording systems etc., of different sensor types, sizes and resolution need manufacturing facility.

- Fabrication of sensors and creation of calibration facilities are to receive first priority, which can be followed by establishment of facilities for manufacture of the complete instrument.

- Constitution of a working committee with specialists in instrumentation, agrometeorologists and potential manufacturers is recommended to provide an action plan on all aspects of indigenous substitution for the above instrumentation.

Vision: *Manufacturing and calibration facilities are created and sensors for agrometeorological studies are available off the shelf within the country.*

Leaf wetness duration recorders:

Among instruments, special mention has to be made about "duration of leaf wetness" measurement. For the incidence, multiplication and spread of crop pest /disease organisms, this is the most important weather parameter. Though empirical estimates are made, they are not very successful, and nothing can replace actual measurement of leaf wetness duration with automatic recording facilities. Plant pathologists and entomologists consider this information very crucial for pest / disease development predictions. This is a high priority area, which deserves thrust.

- Urgent steps should be taken to encourage development and manufacture of leaf wetness duration recorders in the country and good demand for this instrument exists.

- As an interim measure, empirical and mathematical expressions developed for estimation of leaf wetness may be validated with the few leaf wetness measuring recorders available in the country.

Vision: *Successful development of leaf wetness duration recorders takes place in the country in the next five years. Leaf wetness duration maps based on such measurements for the different weather scenarios, seasons and regions in the country would be available for reference.*

8.4.4.2 *Automatic weather station network for agricultural operations:*

Presently several agricultural research institutions have imported automatic weather stations for specific research projects from different manufacturers abroad. Installation of new stations and networking these stations is considered useful for regional scale studies and for agricultural operations. This could be the goal for the next decade.

While this is essential in principle, there are constraints to a networking of automatic weather stations at the present stage, which can be examined by a working group. The following action is suggested.

- Identify suitable regional networks for installing automatic weather stations, which would be useful for agricultural operations
- Automatic weather stations may be installed at inaccessible and remote areas, or for specific research projects at other places
- Take steps to reduce the time lag between time of surface observations, and data communication to a central location and its access to various user agencies at the earliest possible hour in the day
- Promote research to develop management packages on regional scale using hourly data on surface weather elements for irrigation, live stock management and forestry and other agricultural operations
- Training to be imparted in maintenance of automatic weather stations and data management

Vision: *Regional automatic weather station networks are fully established. Models and packages for using hourly weather data for irrigation/ livestock management, and in forestry are available. Near real-time hourly surface weather data from such networks are utilized for agricultural operations.*

8.4.5 Agromet Databank: Database Management

The acquisition of pertinent agrometeorological data, processing, quality control, archival, timely access and database management are important components that will make the information valuable. Since agrometeorological data is collected from cropped fields with several treatments, for several specific and defined purposes, the design for data collection, accuracy, and management of these data are on a different footing than that of a generalized climate database.

Varied nature of Agromet database

Agromet database consists of manual observations, automatic weather stations, remotely sensed data with a wide variety of time and space scales—from seconds to days, weeks to months, at micro- meso- and macro space scales of very different types of land use—from bare soils to cropped fields and agro-forestry systems. Extensive facilities both by way of equipment and personnel are needed for successful management of such a varied database. The databank unit in Agrometeorology functioning at CRIDA, Hyderabad is handling the job of database management in agrometeorology. A website is also functioning from this center. For full utilization of this as a national facility, the following recommendations are made.

- Crop-weather data from all ICAR coordinated projects, ICAR institutes on all crop species, veterinary, livestock, dairying and animal husbandry institutes and SAUs should be communicated by the respective institutes periodically (preferably every week) to the Data Bank in Agrometeorology as a routine.

- This should be made mandatory and urgent action is required by ICAR/DST/IMD/SAUs to bring this into operation at the earliest.

- The exact type of data to be communicated, modes of communication and the format can be decided in consultation with the scientists manning the Data Bank in Agrometeorology.

- Since studies on impact of climatic change and variation are underway in the country and planned for the future on a large scale, action is also needed to locate past data recorded by the several institutes concerned with agromet data, for archival at the Data Bank in Agrometeorology. This needs strengthening the personnel, updating and upgrading database management facilities (hardware and software) at CRIDA by ICAR from time to time.

- Periodical review of these facilities (once in three years) should be made mandatory.

- Simple procedures, without compromising on the security aspects if any, should be evolved for access to the database. Clear guidelines should be framed for data access / retrieval and widely circulated for the benefit of all concerned so that website is utilized to its full potential.

Vision: *All types of agromet data pertaining to weather, crop / animal growth and yield / products are available at the data bank in agrometeorology for access to users.*

8.4.6 Training and Capacity Building

8.4.6.1 Human Resource Development in Agricultural Meteorology

Training of personnel in meteorology, climatology and agricultural subjects both (basic and applied aspects), is an urgent need that was recognized as early as 1976 but yet to be fully realized. There is dearth of fully trained personnel in agrometeorology. It is essential to start ***interactive programs*** i.e., training of agrometeorologists in agricultural disciplines confining to material relevant to interactions with weather, and *vice versa*. The thrust areas in human resource development in agricultural meteorology required are:

- Priority attention to be given to human resource development in all its aspects.

- To complete the process of opening of independent 'Departments of Agrometeorology' in all Agricultural Universities as envisaged by the National Commission on Agriculture in 1976.

- Initiation of PG programmes in agrometeorology in all universities.

- Recognition of ICAR institutes for PG and Ph. D. programs and theses work from recognized universities in the country.

- Involvement of agrometeorologists working at ICAR institutes, in university teaching and programs and their recognition as co-advisors.

- Identifying 'Centres of Excellence' in specified aspects of agrometeorology and providing facilities for training and research at advanced level with necessary financial support.

- Strengthening of facilities at teaching institutions for training more personnel in agricultural meteorology and agricultural climatology at postgraduate and doctoral level.

- To provide training to agrometeorologists in basic principles of meteorology, basic climatology, weather forecasting and weather analysis, micrometeorology, evapotranspiration and agroclimatic analysis.

- To provide for elementary courses in meteorology and climatology at undergraduate and graduate levels, common for all streams of students of agricultural disciplines.

- To organize diploma, certificate and vocational courses in specialized topics of agrometeorology.

- To design composite but separate syllabi including relevant material from (i) agricultural meteorology / agricultural climatology and (ii) from each of the sister disciplines separately at post-graduate and doctoral level in the universities. Syllabus has to be carefully designed so that entomologist or pathologist need not be burdened with all topics in agrometeorology and *vice versa*. Only topics relevant to both which aid interdisciplinary research and teaching may be considered for inclusion in such syllabi.

- To design short-term composite workshops and common programs for training in-service agrometeorologists/agroclimatologists in sister agricultural disciplines and *vice versa. This is a need expressed by several scientists in response to questionnaires.*

- To design and organize joint in-service training programs following integrated syllabi–- syllabi containing agrometeorology and portions of each of the sister agricultural disciplines separately, which are considered more relevant to crop-weather interactions.

- Short term training courses cum collaborative interactive workshops may be conducted with individual groups with common interest (targeted groups) such as (a) Irrigation Engineers & Agronomists, (b) Entomologists, Pathologists and Plant Protection officials (c) Agricultural extension experts and field-workers (d) Statisticians and other scientists concerned with crop yield predictions (e) Cropping-pattern Planners etc.

- In the above, top priority must be given to the training of persons in the interpretation and use of agromet advisories. Requirements of the different groups for the type of agromet information they need, are to be clearly identified. Such programs can be designed and organized by mutual consultation among concerned scientists from provider / user organizations such as DST, ICAR, IMD, Plant Protection Directorate, and State Directorates of Agriculture, and SAUs.

- To organize seminar cum hands-on workshops on specific and limited but significant topics which have practical utility in agricultural operations

- Free mobility of scientific personnel between central institutions and state universities though accepted in principle, continues to be a long drawn unattractive prospect because of administrative bottlenecks for deputation, salary fixation and determination of qualifying service etc., even after retirement. These are deterrents for free mobility and require further streamlining

- Provision of 'Visiting fellowships' for three to six months with protection of salary, continuity in qualifying service may solve this problem so that scientists with capacity to do lead research or do teaching can have a stint at sister institutes which can utilize their services (Similar to DST-SERC Visiting Fellowships).

- **Vision**: *Fully trained agrometeorologists are available to meet demand. All the SAUs have departments of agrometeorology pursuing PG programme in agricultural meteorology. Vocational and certificate training is available and all ICAR institutes and colleges under SAUs have agrometeorology divisions. All state and regional meteorological centres of IMD have an agrometeorologist. Consultancy services in agrometeorology are available.*

Capacity building for developing dynamic simulation models

In this connection it is not out of place to mention that while a few agrometeorologists in the agricultural institutions have gained experience in applying the crop-weather simulation models developed abroad, several of them lack computer programming skills which is a serious limitation. This has been a major handicap for those merely applying the software, without any understanding of the source codes. Intensive training has to be provided in writing programs in Fortran, C++ and CSMP or other simulation languages, which are frequently used in agrometeorology. The objectives are (a) to ensure understanding of the source codes of borrowed programmes by the user scientists and (b) also to encourage scientists to write their own programmes. This is a thrust area needing immediate action. Steps recommended are:

- At the post graduate level, software development and simulation programming should be included as a core/mandatory course with hands on exercises.

- As an interim measure, training workshops may be conducted for agrometeorologists who are not trained in software development, at two or three agricultural research institutions in the country for about three weeks.

- These should be followed immediately to provide further hands-on personalized training (not more than two trainees per teacher scientist) to the same trainees for a minimum period of six weeks by attaching them to individual programmer scientists located at different institutes, familiar with simulation program writing and crop-weather modeling using dynamic approach.

- These targeted training programmes may be liberally supported by DST and ICAR. Project Coordinator (Agrometeorology) of AICRPAM (ICAR) may act as nodal officer for such programmes and work out modalities.

Vision: *Training in computer programming for development of crop-weather dynamic simulation models is made a routine by the year 2010. It becomes a core course with sustained practical exercises for students of agrometeorology / agroclimatology in all teaching and research institutions and they have capacity to write simulation programs.*

Preparation of Manuals and Reports in Agrometeorology and Agroclimatology:

There is lack of teaching material in agrometeorology/ agroclimatology. A few textbooks by Indian authors have appeared since 1990s but these are not presented in a structural mode. Such textbooks are not available even in the international market. Presently teachers and the taught depend on the notes culled out from research papers published in journals or that passed on from the teachers to students. Unlimited scope exists in this field at present. Sponsored projects from national organizations may enthuse the concerned teacher- scientists to take up the task of generating such literature in a systematic and structured pattern for use of student community. This has been a long felt need, which requires to be fulfilled.

Meteorology and climatology for agriculture, micrometeorology, agroclimatic analysis, crop-weather simulation modeling, crop yield forecasting, crop water balance, agrometeorological and agroclimatological aspects of subjects like entomology, plant pathology, agronomy, agricultural engineering, agricultural statistics, plant physiology, horticulture, animal sciences are some of the subjects in which text books, practical manuals, guidelines for operational agriculture are urgently needed. Suggestions are as follows:

- Identified experts may be invited to write text books at graduate and post graduate level courses to cover the course content as per syllabi prescribed by the universities. Proposals may be invited in a project mode.
- Similar action is needed to organize production and publication of:
    - Manuals of procedures for computations in agrometeorology and agroclimatic analysis
    - Guidelines for the upkeep, maintenance and care of the equipment used for agrometeorological work
    - Guidelines for data sampling from cropped fields for the different instruments used
    - Audio-visual aids for teaching and also for agrometerological activities in general
- All these may be peer reviewed before publication by subject matter experts

Vision: *Material like textbooks, guidelines, manuals in both theory and practices, upkeep of instruments, installation procedures etc in agrometeorology are extensively available for reference of user community.*

8.4.7 Linkages with other Institutes - National and International

Good coordination has been noticed in linkage with national and international institutes with respect to programs in agrometeorology. DST, ICAR, IMD, IITM, IITs, IISc., SAC, SAUs are some of the national organizations which have been supporting research projects, workshops, seminars and training programmes at various levels in agrometeorology. At international level, the linkages are with ICRISAT, FAO, UNDP, WMO, ACIAR (Australian Centre for International Agricultural Research) and INDO-US Aid program in Agrometeorology. These have proved useful in exchange of experts and scientists, training, augmentation of instrument facilities, and conducting seminars.

However, these have been few and far between, considering that activities in agrometeorology had been initiated in the 1930s in the country. Such inter-institutional activities are to be augmented through identified and specialized programs of training, exchange of experts and scientists. Linkages among institutions may be developed in the following areas needing collaborative efforts.

- Joint/collaborative programmes at national and international level may be supported in project mode by inviting specific proposals from the agricultural research institutions in the country for augmenting research and teaching and training facilities, exchange visits by scientists in upcoming fields of agrometeorological research,

- Land surface process experiments, crop-weather interactions in the boundary layer, impact of climatic change / variation on agriculture, air pollution and plant injury, development of EXPERT Systems for operational agriculture based on weather forecasts, studies on micrometeorology of crops / animals etc., are some of the areas that need assistance through international linkages.

- At national level, weather and climatic data exchange, inter-institutional training programmes concerning agrometeorology and sister disciplines, coordinated targeted programmes for development of regional operational weather based agroadvisories, regional surveys of cropped areas for development of strategies for disaster management in areas influenced and affected by adverse weather systems like cyclone, floods, droughts, pest/disease epidemics are some of the areas for collaboration and coordination through inter-institutional linkages.

- Real-time weather and crop data exchange among several institutions within the country is one area that is causing concern. An agreed action plan among all the stakeholders is the need of the hour, which can be achieved through inter-institutional collaboration and mutual procedural agreement. A high level committee may be constituted to examine this problem.

Vision: *Inter-institutional collaboration is further strengthened at national and international level in the field of agrometeorological activities.*

Chapter 9

CONCLUDING REMARKS

Within the resource availability over the past five decades, research, development, teaching and extension in agrometeorology had shown reasonable progress. Whether it is yield forecasting, rainfall characterization, water balance, pest disease relations with weather, agroclimatological analysis has been the mainstay and several regressions had been developed and updated. Some of these are in use mainly for crop yield forecasting on regional basis. Database is more location specific and there is need for extending this to regional basis.

Rainfall probability analysis is extensive but not put to potential use. Post mortem analysis has been done and the information has to be integrated with real time crop weather information to be of use for agricultural operations. In-season monitoring has to be strengthened by improving personnel, equipment and in-service training. User requirements are reasonably known, but user targeted orientation in research is thoroughly inadequate. This should be a major objective in all aspects of agrometeorological or agroclimatological research.

On human resource development side, while in-service training facilities have been satisfactory, academic training of personnel at the SAUs, the recommendations of the National Commission of Agriculture as per, are yet to be implemented. This is an area for concern, since, in the current and proposed development of risk management strategies for agriculture in general, and disaster management (pest/disease, drought, flooding, heat/cold waves etc.,) in particular, urgent action is needed. These events are governed by weather systems over large areas and dynamic in nature, extending beyond state boundaries, are to be closely monitored for any ameliorative action to be taken. Integrated and holistic approach is the need of the hour since agrometeorological data are the base for predicting the events as well as when they occur and move over to other areas or dissipate. Application of dynamic simulation models, remote-sensing techniques, ground truth are to be integrated with synoptic weather and short/ medium range weather forecasts and contingency plans.

The point to note is that beyond correlations and regressions with crop/pest parameters on which there is no dearth of information, research in agrometeorology has substantial contribution to make towards understanding several events in crop growth —irrigation requirements, pest/disease development, fertilizer dosage selection, microclimate modification etc., on one side, and harvest, storage transport and marketing etc., on the other. Possibilities are immense in agrometeorological research and development of forecasting models, and Expert systems with user-requirement targeted approach would be a viable solution.

Again, for achieving this, one has to come back to strongly supporting programmes on (a) human resource development not only at postgraduate level, but at diploma and certificate level, (b) creation of agromet cells at all national level crop-based research institutes (c) involvement of interdisciplinary teams for conducting joint courses with common but not a general syllabus (d) creation of facilities for in-season crop weather data monitoring and communication at as many field sites as possible (e) crop-weather data exchange on a day-to-day basis (f) indigenous development of instrumentation (all types of weather sensors) with calibration facilities and (g) encouraging preparation of manuals, guideline books for computations and text books of quality, in agrometeorology and agroclimatology. For the success of weather-based agroadvisory services for agricultural operations, these are priorities for the immediate future, and other points have been adequately discussed in the document.

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ABBREVIATIONS AND ACRONYMS

AASU	Agro Advisory Services Unit
AAU	Anand Agricultural University
ACIAR	Australian Centre for International Agricultural Research
AICRPAM	All India Coordinated Project in Agricultural Meteorology
ARPU	Agroclimatic Regional Planning Unit
AWS	Automatic Weather Stations
CAgM	Commission for Agricultural Meteorology
CAPE	Crop Acerage and Production Estimation
CASAM	Centre for Advanced Studies in Agricultural Meteorology
CAZRI	Central Arid Zone Research Institute
CBD	Convention on Biological Diversity
CRIDA	Central Research Institute for Dryland Agriculture
CSMP	Computer Simulation Modeling Program
DST	Department of Science and Technology
ENSO	El Nino and Southern Oscillation
FAO	Food and Agricultural Organization
FASAL	Forecasting Agricultural output using Space Agrometeorology and Land based observations.
GAU	Gujarat Agricultural University
GCM	Genera l Circulation Models
GHG	Green House Gases
GIS	Geographical Information System
HAU	Haryana Agricultural University
IARI	Indian Agricultural Research Institute
IASRI	Indian Agricultural Statistical Research Institute.
ICAR	Indian Council for Agricultural Research
ICRISAT	International Crops Research Institute for Semi Arid Tropics
ICRP	Indian Climate Research Program
IGAU	Indira Gandhi Agricultural University
IGBP	International Geosphere Biosphere Programme
IISc	Indian Institute of Science
IIT	Indian Institute of Technology
IITM	Indian Institute of Tropical Meteorology
ILEAPS	Integrated Land Ecosystem Atmospheric Process Studies
IMD	India Meteorological Department
IPM	Integrated Pest Management
ISRO	Indian Space Research Organisation
IVRI	Indian Veterinary Research Institute
LAI	Leaf Area Index
LASPEX	Large Area Surface Processes Experiment.
NADAMS	National Agricultural Drought and Management Systems
NARP	National Agricultural Research Programme
NATP	National Agricultural Technology Program
NBSSLUP	National Bureau of Soil Survey and Land Use Planning
NCIPM	National Institute for Integrated Pest Management

NCMRWF	National Centre for Medium Range Weather Forecasting
NDRI	National Dairy Research Institute
NIH	National Institute of Hydrology
NRC	National Research Centre
NRSA	National Remote Sensing Agency
PAMC	Program Advisory and Monitoring Committee
SAC	Space Application Centre
SAU's	State Agricultural Universities.
SITE	Satellite Instructional Television Experiment
TNAU	Tamil Nadu Agricultural University
UNCCD	United Nations Convention to Combat Desertification
UNCED	United Nations Conference on Environment and Development
UNDP	United Nations Development Programme
UNESCO	United Nations Educational, Social and Cultural Organization.
UNFCC	United Nations Framework on Climate Change
WMO	World Meteorological Organization