CHAPTER 1

Origin of Developments Relating to and/or in Agricultural Meteorology

In the 4th Century. Aristotle, whose "Meteorologica" elevated Meteorology from the realm of mythology to science, had observed "Annus Fructificat Non Terra" meaning it is the year (read weather) and not the soil that determined crop yields. Rural proverbs found in almost all Indian languages abound in giving thumb rules for (a) anticipation of local weather (b) timing of agricultural operations in light of expected weather and (c) advanced assessment of crop prospects on basis of realized weather. Basu (1953) found no scientific basis for the proverbial beliefs. Nevertheless, the rural proverbs reveal the anxiety of farmers to know in advance the likely weather situations for crop operations and yield assessment. Thus, the knowledge of farmers on influence of weather on crops is times immemorial.

Venkataraman and Krishnan (1992) in their book "Crops and Weather" have given an historic narration of the various topics of studies covered in the chapters of the book. It was felt that culling out from the above book and other sources, a chronological bird's-eye account of the origin of and developments in and related to agrometeorology can be made to inculcate in students of agrometeorology an appreciation of some pioneering work and concepts that have laid the foundation for many lines of work currently in use in applied agrometeorology.

In light of the above, some pioneering work on crop-weather studies, prior to acceptance in the 1930s of agrometeorology as a specialised science, are cited and their relevance to appropriate fields of applied agrometeorology currently in use are briefly mentioned. Initiation of important lines of work and significant developments are presented decade wise from 30s to first decade of the current century.

1.1 Pioneering Work

1.1.1 Degree-days

Reamur (1735) was the first to attempt a quantification of agrometeorological relationships by trying to relate duration of crop-life in terms of accumulated mean temperatures. Reamur's work remained dormant till it was resumed by Abbe (1905). The concept of Reamur of accumulated mean air temperatures have been extensively adapted in the 20th Century for understanding and/or explaining phasic development of plants. In these, accumulations (i) above a specified mean air temperature depending on crop (ii) night air temperature (iii) excluding values of temperature (a) above a specified maximum and (b) below a specified minimum (iv) product of photoperiod and temperature called Photothermal Units and (v) products of hours of bright sunshine hours and temperature called Heliothermal Units have been used.

1.1.2 Photoperiodism

The observations in the differences in flowering behaviour of avenue trees subject to the influence of street lights compared to those in the dark led Garner and Allard (1920) to the discovery of Photoperiodism. This concept led to the classification of plants as long-day, short-day and neutral types depending on their photoperiodic requirements for flowering. Garner and Allard 1920) themselves classified some plants which will not flower under photoperiods of less than 12 hours or more than 14 hours as intermediate types.

Flowering of crops on account of photoperiodism is agriculturally undesirable as it gave little scope for agronomic manipulation in management of crops. The need for removal of photo-sensitivity became crucial and was successfully done by plant breeders by evolving photo-insensitive varieties of many crops. Further findings, relating to photoperiodism and their agronomic and genetic applications, are given in Chapter 2. The main findings relating to photoperiodism are that

(i) the continuity in night period was the operative factor
(ii) the photoperiodic effect was exerted even at intensities as low as in moonlight
(iii) the red spectrum is the most active in photoperiodic induction
(iv) either mature leaves or growing tips of plants are the receptors of the photoperiodic stimulus and
(v) the photoperiodic effect could be modified or even eliminated by influence of temperature, especially night temperatures.

1.1.3 Pests and Diseases

Potato famine in Europe and North America, due to Potato Blight, in the middle of 19thcentury and Chestnut Blight in USA by end of 19th century triggered the need for an understanding of weather relations of diseases. Studies of pests in relation to weather are complicated by the operation of factors like mobility and hibernation through which pests can avoid encountering adverse weather. The investigations in the 1920s pioneered the work on weather aspects of incidence of pests of rice (Mishra, 1920; Ghosh, 1921; Austin, 1923; Ramachandra Rao, 1925; Hegdekatti, 1927).

Pierce, et. al. (1912) identified some natural enemies of the Cotton Boll Weevil and demonstrated their usefulness in control of the Cotton Boll Weevil in U.S.A. They had, advocated adoption of a sound climatic approach for biological control of pests. It is worth nothing that neglect of the climatic aspect led to the failure of the attempt in biological control of the Sugarcane Mealy Bug in Egypt and Palestine (Uvarov, 1931). Biological control of pests and diseases through introduction, from exotic regions, of their natural parasites/predators based on the climatology of places and periods of their origin and introduction is now an accepted and widely used non-chemical method in the fight against crop pests and diseases.

1.1.4 Others

De Saussure can rightly be called the pioneer in the field of pathways in photosynthetic fixation of carbohydrates as he had hinted at the

Crassulacean Acid Meabolism pathway in photosynthesis as early as 1804 and the same was confirmed in 1892 by Aubert. The work of Money (1883) on the climatic needs of the Tea crop can be held as a pioneering study on the assessment of climatic requirements of crops. Edward Mawley, President of The Royal Met. Society had observed in 1890 that "there are few sciences so intimately connected with each other as Meteorology, Agriculture and Horticulture". The above set the tone and emphasised the need for development of Agricultural Meteorology as a scientific discipline.

Work of (a) Arnon (1909) and Wiley (1901) on the influence of temperature on flowering of Sugarcane and of latitudinal spread of Sugar beet respectively (b) Howard et.al. (1914) on the effect of environment on quality of Wheat (c) Bates (1911) on influence of windbreaks on crop yields and (d) Koppen (1918) on climatic classification, can be cited as pioneering studies in applied agrometeorology. The concept of Relative Transpiration of Livingston, (1906) can be considered the fore-runner in the meteorological determination of crop water needs. Soil temperature had been recognised as an ecological factor in early 1920s (Jones and Tisdale, 1921). The observation of Howard (1924) that wheat production in India is a gamble on temperatures gained as much attention as the adage that the Indian Budget was a gamble on the monsoon.

1.2 Recognition

International recognition of Agrometeorology as a scientific discipline came about in 1913 with the formation of the Commission for Agricultural Meteorology, CAgM, in 1913 by the then International Meteorological Organisation, IMO. Due to World War I, CAgM had to be reconstituted in 1918 and had its first meeting in 1923. H. Hooker, President of the Royal Meteorological Society had, in 1921, suggested the use of Statistics to correlate crop yields with weather variables. A crop weather scheme was begun to be operated in U.K. in the 1920s. As a result of the deliberations of The Royal Commission on Agriculture in India constituted in 1928, the Division of Agrometeorology came to be established in 1932 at Pune under the India Meteorological Department. This catalysed subsequent international developments in the field of Agrometeorology.

1.3 Developments

1.3.1 1930s

Studies on (a) profiles of temperature and humidity (i) over and close to many natural surfaces by German workers (Geiger, 1930) and (ii) inside crop canopies vis-a-vis that in the open by Indian workers (Ramdas et. al. 1934) (b) likely contribution of Dew to water needs of crops (Wadsworth, 1934) (c) use of January temperatures in anticipating incidence of Downey Mildew of Tobacco in Southern U.S.A, which may be deemed as a forerunner in forecasting diseases using the degree day concept (d) the assessment of the stage at which a pest caused economic damage (Pierce 1934), which later led to the development of the concepts of economic injury level and Biofix, were of a pioneering nature.

The need for a separate network of stations recording in a farm environment meteorological observations of interest to agriculture not recorded routinely at synoptic weather observatories, recording of observations at 0700 and 1400 hours Local Mean Time to obtain range of weather parameters from observations with only eye reading instruments were recognised early. Standardization of field lay out and sampling procedures, on a crop-wise basis, for (a) assessing initial and final population density (b) recording (i) phenological and phenometric crop attributes and (ii) yields and (c) determining extent and intensity of incidence of major pests and diseases formed the basis for operation of All India coordinated crop weather Scheme relating to many crops.

1.3.2 1940s

The concept of Vernalisation, developed in the 1940s can be considered a milestone in adaptive agrometeorology and a classic example of adoption of an agronomic strategy to overcome harsh weather conditions. In this seeds of winter wheat are exposed to a chilling temperature of 3 degrees centigrade for a definite period so as to induce shooting on sowing in the pre-winter period such that the seedlings will remain alive under a snow cover in winter, resume growth on advent of spring to complete their life cycle.

Work of (i) Burton, (1941), on the influence of weather factors on viability of seeds in situ and in storage, (ii) Penman (1941) and Staple and Lehane (1944) on weather aspects of evaporation from bare soil

(iii) Mehta (1940) on the exotic origin of wheat Rusts and (iv) Parija (1943) on high temperature vernalisation by pre-sowing treatment of seeds to modify phasic development of plants were notable contributions. The laboratory work of Pradhan (1946) on growth and development of pests leading to the concept of a Biometer in which the temperature graduations in a thermograph are replaced by lines of average development of the pest for a given stage at that temperature and the enunciation, in 1948, of the concept of Potential Evapotranspiration, PET, in USA (Thornthwaite, 1948) and in U.K. (Penman, 1948) and the construction of the first Phytotron at the Earhart Laboratory of the California Institute of Technology in 1948 were landmark developments in the 1940s. The concept of PET has later helped (i) to unify apparently diverse data on crop water consumption and needs (ii) in formulation of weather-based irrigation scheduling of crops and (iii) in isolating and quantifying the role of soil and crop factors on crop water requirements. The phytotron helped in carrying out of intensive studies on the influence of weather factors on growth and development of plants. Enunciation of the concept of Ecological Geography and identification of global agroclimatic analogues (Nuttonson, 1949) for many regions of the world for diverse crops was a significant development. The feasibility of forecasting of Potato Blight from weather data (Cook, 1949) was the fore-runner for weather-based anticipation of and assistance in control operations against many crop diseases.

1.3.3 1950s

The coming into being of the World Meteorological Organisation, WMO as a specialised agency of United Nations in 1951 and inclusion of the Commission of Agricultural Meteorology CAgM as one of the eight technical commissions of WMO were significant developments that fostered global development of scientific and service aspects of Agricultural Meteorology.

Discovery of the Calvin cycle in formation of photosynthates leading to the identification of crops as C3 types was an important development of the 1950s. From studies in climate-controlled chambers, emerged another important discovery, namely the concept of Thermoperiodicity (Went, 1957) i.e., the differential response of crop species to daytime, night-time and mean air temperatures (examples: Solanaceae to night temperatures; Papillionaceae to daytime temperatures and Graminaceae to mean air temperatures). Thermoperiodicity should rank in importance equal to the discovery of photoperiodism in crops in the 1920s. Other significant development in the 1950s, were: (a) use of monomolecular films of long-chain alcohols for reducing evaporation from free water surfaces (Mansfield, 1958) (b) development of various types of lysimeters to measure daily evapotranspiration of aerobic and anaerobic crops (c) opening up of the feasibility of forecasting of pests and diseases from weather data(Bourke, 1955) and (d) enunciation of the concept of Economic Threshold Limit, ETL for initiation of control action against pests using data from insect traps.

The beginning of Dynamic Crop Weather Simulation modeling can be traced to the 1950s due to publication of pioneering papers on (i) plant development (Monsi and Saeki,1953) and (ii) plant modelling (Dewit, 1959) and (iii) fundamental work on plant photosynthesis and crop productivity (Davidson and Philip. 1958; Went, 1958).

1.3.4 1960s

Development of the first model on water transfer in the soil-plant-atmosphere continuum by Gardner (1960) and development of models for (i) assessment of photosynthesis of crop canopies (De Wit, 1965), which was the fore-runner in the development of Dynamic Crop-Weather Simulation Models (ii) concepts initiated in the 1950s (Ross, 1966) leading to the expression in mathematical terms of (a) plant growth and (b) plant responses to environmental conditions (Duncan et. al. 1967) need special mention.

The launching of the Polar Orbiting satellites gave a boost to development of Satellite Agricultural Meteorology as one could observe any place on Earth and view every location twice each day with the same general lighting conditions due to the near-constant local solar time. Being closer to earth the Polar Orbiting Satellites gave scope for a much better resolution than their geostationary counterparts.

The Green Revolution brought about by the breeding and use of short-statured hybrid varieties of many grain crops leading to quantum jumps in unit area yields of many crops was the most important development of the 1960s.

The world's first truly operational Geographical Information System, GIS was developed in Canada in 1960. GIS later came to be used extensively to receive satellite-sensed agrometeorological data and produce outputs of agrometeorological importance. Formation in 1964 of the Laboratory for Computer Graphics and Spatial analysis and development of a number of important theoretical concepts in spatial data handling were important developments.

Since pan evaporation integrates the effects of all factors affecting water needs of crops, its role in crop water management is obvious. However, evaporimeters in various countries vary in dimensions, material of construction and manner of maintenance, mounting and measurement. Their readings were vitiated by bird visitations. Thus, the programme for international comparison of evaporimeters drawn up by the Commission of Instruments and Methods of Observation, CIMO of WMO in 1964 involving principally the USA Class A Pan, Russian GGI 3000 evaporimeter and the Russian 20 m^2 tank was an important endeavor. Evaporation from the Russian 20 m^2 tank represented evaporation from a shallow lake which is equivalent to Potential Evapotranspiration.

An Interagency Group on Agricultural Biometeorology was formed by FAO, WMO and UNESCO. Rigorous field studies on physical processes in crop environment like fluxes of momentum, energy and moisture and intensive phytotronic studies on physiological processes of crops had been undertaken. The conservative nature of yield per day per unit area of crop cultivars in a given season was established (Swaminthan, 1968). The mathematical breakthrough of Incomplete Gamma Distribution (Thom, 1966) helped in analyses of rainfall amounts in short time-units and in determination over short time-units (i) minimum assured rainfall at a given probability level and (ii) probability of realising a given amount of rainfall and was a significant contribution in the field of dryfarming meteorology. The discovery of the Hatch-Slack photosynthetic pathway led to identification of plants as C4 types. Enunciation of the concept of Critical Disease Level, CDL which relates to the stage of development of the disease before which control operations are not required and after which control operations will be ineffective (Shoemaker and Lorbeer 1969) helped in timely and effective control operations against crop diseases based on data of spore traps and was another major development.

1.3.5 1970s

Appointment of a Rapporteur by CAgM of WMO in 1974 to study the application of remote sensing techniques to solving of agrometeorological problems was an important step that gave a boost to the development of satellite-sensed agromet parameters and GIS applications in agrometeorology. Analyses of data of about 10 years, recorded under the International Comparison of Evaporimeters, brought out the fact that the ratio of evaporation from pans to that from the Russian 20 m^2 tank varied with the rate of evaporation. This revealed, that for use of Pan Evaporimetry for scheduling irrigation of crops, ratio of EP to PET must be determined on a season-wise and region-wise basis. Standardisation of procedure by FAO for computation of Wind Erosivity Index was an important step.

Prior to 1970 crop-weather relationship studies used to be conducted in Phytotrons or environmental chambers in which the ambient conditions were kept constant and hence quite different from the macro and micro-climatic conditions experienced by crops in the field. In field crop trials, phenological and phenometric attributes could be related to positive and negative deviations from normal values of all meteorological parameters except Carbon Dioxide in which higher values never prevailed in the past. In view of the expected increase in Carbon dioxide concentration under global warming, it was necessary to study gas exchanges between the crop and its environment under higher level of Carbon Dioxide. In this context, a beginning was made by Heagle et. al. (1973) to study plant processes under field conditions through the use of Open Top Chambers, (OTC). The OTCs are plastic enclosures, with an open top, constructed of an aluminum frame covered by panels of PVC plastic film. Air enriched with CO_2, is pulled into the bottom of the chamber, and then blown through the open top of the chamber. OTCs, inexpensive and easy to construct and maintain, are not suited for the study of large vegetation.

The next development in the study of gas exchanges in natural cropped conditions was the design and construction in 1978 of the Soil-Plant-Atmosphere Research System SPAR, by Phene et. al. (1978) at Florence, South Carolina, USA. In SPAR, the area earmarked for the study is allowed to receive natural sunlight. Soil and aerial environments are precisely controlled in the earmarked area and gas exchanges are rapidly and automatically measured under natural sunlight with attendant variations in solar radiation intensity and its spectral distribution. The latter features of solar radiations are difficult to be obtained in artificially lit Phytotrons and growth-chambers.

International crop research institutes with agerometeorological units were established under the Governing Council for International Agricultural Research, GCIAR, to meet needs of specific climatic zones and to analyze crop-weather data gathered on specific crops on a global scale. There was a spurt in the activities of FAO in Agrometeorology under its Environment Natural Resources and Services Division. The FAO scheme on agrometeorological monitoring and forecasting yields of rainfed crops based on rainfall budgeting and water satiation concept was started. The separation of the evaporative component of evapotranspiration under incomplete crop cover and irregular wetting of soil surfaces (Ritchie, 1972) was a land mark development. The Satellite Instructional and Television Experiment, SITE, in India in which agricultural, agrometeorological and meteorological experts jointly reviewed the weekly field-position of crops along with concurrent meteorological data and the anticipated weather, to issue advisories for crop operations, became the fore-runner for initiation of Agromet Advisory Services in India. Methodology for assessment of wind erosivity index was standardised by FAO. A computerised system for forecasting crop diseases was initiated (Castor et. al. 1975). Assessment of areal spread and health of crops by satellite imagery was commenced. Studies on Radiation Use-efficiency and influence of elevated CO_2 and shading on crop yields, which have a bearing on assessment of crop prospects in a warm climate, were initiated.

The development and use of the concept of Biofix (Riedl et al. 1976), which relates to the date of occurrence of a particular event in the life of an organism was an important development leading to the use of catches in insect and spore traps for minimal and effective control operations against pests and diseases.

Continuation of the work on Dynamic crop weather simulation model (Dewit et. al. 1970; Curry 1971; Dewit and Goudrian, 1974) led to the formulation of Dynamic Crop weather Simulation Model, on Sorghium by Arkin et. al. (1976).

1.3.6 1980s

Formation of The Intergovernmental Panel on Climate Change (IPCC), an international organization with a mandate "to assess on a comprehensive, objective, open and transparent basis the best available scientific, technical and socio-economic information on climate change" initially by WMO and UNEP in 1988 and later endorsed by United Nations , was an important development.

WMO and FAO actively collaborated on (a) provision of meteorological aids for prevention of desertification (b) application of climatic data for effective irrigation planning and management and (c) weather-based forecasting of crop yields. WMO standardised the procedure for computation of rainfall erosivity. Flooded rice was identified as a significant source of atmospheric Methane. Noticing of the increase in difference in yield in farmers' fields with that of a nearby research station with increase in rainfall (Sivakumar et. al. 1983) highlighted a serious deficiency in the lab to land transfer of technology. Delineation of the role of crop physiology in water uptake by crops, studies on influence of CO_2, solar radiation etc., having a bearing on impact of climate change on crops, suggestion for use of decreased respiration rates as a selection criterion in breeding crops for higher yields (Wilson and Jones, 1982) were significant features. The later part of 1980s witnessed a spurt in development of crop models (Sinclair, 1986; Hammer et. al. 1987; William et. al. 1989). Dynamic Crop Weather Simulation Models, DCWSMs were developed and field tested for many important crops. Satellite data were also used to improve output of crop yields from DGWSMs.

An important development was the plethora of Free Air Carbon Dioxide Enrichment (FACE) experiments pioneered by Rogers et al. (1983) and Jones et. al. (1984), who adopted the fumigation methodology (Greenwood, et. al. 1982) used to study effects of air pollutants on crops and adapted the SPAR Technology (Phene et al. 1978). In the FACE experiments, gassing circles of sufficiently large diameter are installed in a field. Inside the circles, the aerial CO_2 concentration can be increased with reference to the natural ambient CO_2 concentration, with automatic control of wind speed and wind direction to maintain the experimental concentration level. In such a set up, Carbon Dioxide is blown from a tank through vertical standing vent pipes into the exposure area. Sensors measure wind speed, wind direction, and CO_2 concentration and a computer control system regulates and monitors the CO_2 releases. The above felicitated the studies on effects of rising levels of CO_2 on crop yields.

The first genetically modified plant, an antibiotic-resistant Tobacco cultivar, was developed in 1983. However, the activity of genetic modification of plants remained dormant for another ten years.

1.3.7 1990s

There was a sudden spurt in evolving of genetically modified, GM plants. GM cultivars for a number of crops were developed in this decade. A very important development in the 1990s was the successful use of high resolution satellite imagery for crop identification, crop area determination, estimation of moisture content of top layers of soil, determination of crop emergence and hence of sowing dates, yield-determining crop attributes, crop phenology, crop moisture deficit etc. These enabled the preparation of crop inventories at periodic intervals on a crop-wise and region-wise basis and led to formulation of methodologies for agrometeorological forecasting of gross, regional crop yields through combination and integration of ground-truth and satellite sensed agrometeorological data (Gommes 1998;Moulin et al. 1998).

The other notable developments in the decade were (a) initiation of in-depth studies on an extensive global scale on (i) the likely changes in direction and magnitude of changes in weather parameters on account of the Greenhouse Effect of anthropogenic origin (b) effects of climate change on crop production in future (c) ways for mitigation of the harmful effects of (i) climate change on crops and (ii) agricultural practices on global warming (d) standardisation of methodology by FAO for determination of temporal march of Evapotranspiration of given crops at given locations and irrigation scheduling thereof (e) decreasing trends in observed Pan Evaporation and computed Reference Crop Evapotranspiration despite increase in temperatures in many parts of the world and (f) studies on likely reductions in water needs of crops in future climate.

1.3.8 First Decade of the Current Century

The decade has been one of achievements and concern as detailed below.

Much of the work mentioned above were being carried in an intensive manner and extensive scale through adoption/adaption of pioneering developments. In this, mention needs to be made of (a) improvements in the provision and end-use of crop-weather agrometeorological advisory services (b) forecasting of regional yields of many irrigated and rainfed crops by use of satellite data/imageries of an agrometeorological nature (c) studies relating to (i) assessment of the adverse influences of climate change on yields of many crops in many regions and seasons (ii) reduction of emission of Methane from flooded rice and GHGs from agricultural operations and (iii) increased Carbon sequestration.

A decreasing trend in rate of increase in crop production of even irrigated crops in the last 15 years due to pollution of air, degradation of soil and contamination of water resources on account of over-use of water and inorganic agrochemicals, production of all crops much in excess of national requirements and high market prices of all agro-industrial crop produce have brought to the fore the urgent need for climatic cognizance in production and protection of crops to ensure agricultural sustainability with environmental conservation and planned, specialised and regionalised production of crops in an economic manner. In this, inadequacy of apparent solutions like GM cropping and national rivers' linking have been brought out. Cooperative farming, organic cropping, optimal and conjunctive use of water resources and integrated management of biotic stresses have emerged as the solutions.

Progress of international collaboration in reduction of green house gases as per committed time bound targets in various regions has been stymied due to the concept of trading in greenhouse gas stocks and dilemma of developing countries' attempts in ensuring development with reduced GHG emissions.

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