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**STUDIES IN THE ANALYSIS OF
WEATHER-CROP RELATIONSHIP ;
A REVIEW OF LITERATURE**

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STUDIES IN THE ANALYSIS OF WEATHER-CROP
RELATIONSHIPS :
A REVIEW OF LITERATURE

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PREFATORY NOTE

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CHAPTER ONE

INTRODUCTION

1.1 Agriculture is purported to be the economic sector closest to perfect competition except for the usual assumption of complete mobility of factors of production and dependence on weather. It is a biological 'industry' largely affected by natural laws and physical factors over which nobody has much control - weather and biological 'cycles' being the prime examples. This makes the process of production in agriculture and agriculture-based industries discrete. As against this, economic activity outside agriculture is relatively much more subject to managerial control because of its non-biological production processes which are also continuous in nature, and also because of the short-period and fully controlled amplitude of the cycle of production in most of them.

1.2 The factors which affect agricultural production and especially crop production can be classified into several categories:¹

- 1) environmental - relevant to geography, geology, climate;
- 2) economic - relevant to market conditions, price relationships, wages;

¹ Oury, Bernard : A Production Model for Wheat and Food-grains in France; North-Holland Publishing Co., Amsterdam, 1966, pp. 7.

- 3) technological - relevant to the various forms of technology involved;
- 4) institutional - relevant to law, tradition, and government policy.

Associated with these factors arise uncertainties among which the technological and sociological/institutional uncertainties are of particular importance to non-agricultural industries. In the case of agricultural production, the farmer is primarily concerned with price and weather uncertainties. Weather uncertainties result in wide and irregular variations in the production co-efficients for a given technique; and are almost universally present in the various lines of agricultural production. While it is possible to control soil moisture to a certain extent through irrigation, variations in other climatic factors like temperature, sunshine, humidity, cloudiness, etc., are hardly controllable. Therefore, there is a continuous effort at understanding the relation between variations in weather and crop production.

1.3 There have been two broad approaches to this question. The first is to examine over long periods any periodicity - cycle in agricultural production and relate it to weather cycles or cycles in other natural forces that affect weather. This would not only explain variations in farm production over long periods, and, depending on the importance of agriculture, in total national activity, but also may provide a basis for general forecasts.

1.4 The success of this approach is contingent not only on our knowledge of the weather factors determining yield, but also on our ability to predict weather. Weather is referred to as the collection of various conditions of atmosphere including such phenomena as rainfall, snowfall, hail, humidity, amount of sunshine, light intensity, atmospheric pressure and temperature, occurring during a definite time period as contrasted with the term 'climate' which is taken to mean the longrun characteristics of weather at a particular place.² The study of meteorological 'cycles' has received attention of many authors, statisticians and economists as well as meteorologists - particularly economists, owing to the possibility it seemed to offer of an explanation of economic cycles by meteorological and cosmic events. Inadequacy of reliable data is one major hindrance in such studies, particularly in the presence of a bewildering number of apparent 'periodicities'. Authors have tried to use indirect data such as prices of agricultural products, variations in the levels of lakes, variations in the rate of growth of trees and so on. Jevon's attempt at correlating sun-spot period and harvest fluctuations and the latter with economic cycles is worth mentioning in this context.³ But conclusions drawn from such studies could not be maintained after further careful studies.

2 Stallings, James L. : A Measure of the Influence of Weather on Crop Production; JFE, Dec., 1961.

3 Javons, Stanley W. : Investigations in Currency and Finance (1884).

1.5 Other efforts towards analysis of periodicities include H.L. Moore's cosmic explanation relating commercial crises to eight-year cycle of planet Venus;⁴ Sir Francis Bacon and later Eduard Brueckrner's 35-year cycle (on the average) relating long records of rainfall, temperature, pressure and indirect informations. Sir W. Napier Shaw in 'Manual of Meteorology' lists more than 100 cycles ranging from one year to 744 years which have been claimed at one time or another. Most of these periodicities are of small amplitudes and do not show great regularity as to length of the period. There is no conclusive evidence that any of the periodicities suggested are real. All that can be said is that most of our weather series are not strictly random series, but show a significant degree of serial correlation or interdependence of successive observations. Whether this is indicative of a hidden periodicity or merely the result of a persistent tendency, it is impossible to say. Another kind of attempt in this direction has also been made by Gilbert Walker and T. Okada where they have tried to correlate weather conditions in one region with subsequent weather conditions in some other region with marked time lags between them, but without any reliable and conclusive results.⁵

⁴ Moore, H.L. : Economic Cycles : Their Law and Cause (1914).

⁵ Sanderson, Fred H. : Methods of Crop Forecasting; (Harvard Univ. Press) - 1954, pp. 7.

1.6 Thus the identification of weather cycles has not been easy or fruitful so far. Even if definite weather cycles or inter-regional correlations could be established, the weather forecasts based on them would necessarily be general in character. But variations in crop-yield depend not so much on some overall seasonal or annual index of weather, but on the weather performance at some crucial stages of growth of specific varieties of plants. Therefore the second and the growing line of attack has been on the identification and specification of weather variables affecting the production performance of a crop. The exercise can be two-fold: the first and relatively simpler one is to explain the contribution of weather to the variations of area under crops,⁶ and the second, to the variation in the yield of the crop. The recent theoretical insights into the processes of plant growth and the responses of plants to weather influences as well as the efficient statistical methods have lent strength and credibility to such exercises. The obstacles arising out of lack of adequate data and co-ordination of the efforts in various phases of the problem are also gradually removed with growing co-operation among agronomists, plant ecologists, plant physiologists, meteorologists, economists and statisticians.

6 Correlation studies on acreage and factors like prevailing prices, absolute change in yield per acre and weather factors have been done by many economists. Leading among them are : H.L. Moore (Forecasting the Yield and Price of Cotton; 1917); R.H. Hooker (Correlation of Weather and Crops; Journal of the Royal Statistical Society, 1907); L.H. Bean (The Farmers' Response to Price; JFE, July 1929); S.M. Jacob (Correlation of Rainfall and the Succeeding Crops with Special Reference to the Punjab; IMD Memoirs, 1916).

1.7 Such exercises, if successful will help in answering a number of important questions; and a better understanding and quantification of the weather-crop relationship would have many applications.

1.8 It will help separate the impact of weather from that of other factors - technological, economic and even institutional, on year to year variations in production of crops. This is necessary for judging the performance of the non-weather factors on agricultural production. This is important particularly with reference to developing agricultural countries for the formulation of suitable agricultural policies.⁷ If the resultant increase in crop yields and production is largely due to favourable weather, an effective storage policy might be appropriate;⁸ if it is due to improved technology, policies aimed at cutting back production merit consideration in certain types of economies. Identification and evaluation of independent variables other than weather requires an analysis of yield and production trends corrected for weather - hence, the need of a 'weather-deflator'.⁹

1.9 A precise knowledge of the critical periods of plant growth, through weather-crop research, would make it possible

7 Sharma, J.S. : Crop-Weather Relationships - Areas of Study; Journal of Indian Society of Agricultural Statistics, Dec.1970.

8 Ray, S.K. : Weather and Reserve Stocks for Foodgrains; EPW, Sept. 1971.

9 Stallings, James L. : A Measure of the Influence of Weather on Crop Production; JFE, Dec. 1961.

to protect crops more effectively against unfavourable weather; and would provide the basic feed back to plant breeders to develop varieties more suited to the relevant pattern of weather as revealed in such studies. Planning of crop-rotation and new cropping pattern would benefit from the knowledge of weather-crop relationships. The study of the effects of weather on weeds, diseases and pests can give advance warning for prophylactic measures.

1.10 Such studies might also provide basis for short-run forecasting of crop-production. In the analysis of agricultural supply or the assessment of expected yields over regions, weather influence would appear as an explicit variable to account for the variations instead of being treated as one whose effect is caught in the error term of the estimating function. Regional crop-yield assessment could be useful both at the national and international level for the management of food-security system, planning of food imports and exports, early recognition of areas of developing food-crisis and modification of food policies. An agricultural supply function allowing for weather-inputs could also provide the insight into the economic logic governing resource use and optimising behaviour of individual firms.¹⁰ The weather-crop research can also give a proper assessment of the droughts; and through evaluation of risks associated with the

¹⁰ McQuigg and Doll : Economic Analyses Involving Random Weather Inputs; JFE, 1961, pp. 909.

weather factors, it can help the farmer in assessing how far crop-insurance helps in facing instability.¹¹

1.11 The present study proposes to review in subsequent chapters, the studies made in the field of weather-crop-yield relationships.

1.12 In Chapter II, the general hypotheses regarding the influence of weather are discussed along with some weather-crop analysis models. It also deals with the statistical basis for the specification of weather-crop relationship and the problems arising thereof. Finally, the construction, uses and limitations of 'weather indices' are discussed.

1.13 In Chapter III, the attempt has been made to discuss the different statistical exercises abroad in the field of weather-crop relationship.

1.14 Chapter IV discusses the weather-crop studies in India, where the AICWS and the methodology adopted in the studies are also discussed before going into the individual studies and their findings.

1.15 Chapter V consists of the concluding remarks.

¹¹ Nadkarni, M.V. and P.K. Ghosh : Instability in Rainfall and Agricultural Yields in a Drought-prone District (Tumkur); IJAE, Apr.-June, 1978.

CHAPTER TWO

THE GENERAL HYPOTHESES

2.1 Production of a crop is the resultant of acreage and the yield per acre, which can be expressed as a function of a number of controlled variables like fertilizers, pesticides, irrigation, prices, etc., and an uncontrollable variable comprising various climatic factors like rainfall, temperature, run of dry days, humidity, day-length, etc.. This uncontrollable variable varies according to some undetermined natural laws and thus, causes, unexpected variations in yield and acreage, and hence, in production; - the various climatic factors enter into the production function as exogenous variables. The productivity coefficients of the various endogenous variables in the system differ over space and time, because the magnitudes of the exogenous variables vary.

2.2 Even if the climatic factors follow some repetitive pattern, the production fluctuations would not be proportional unless the relative magnitudes of the effects of these factors on production remain constant over time. The physical frame of reference in agriculture is, however, not invariant with respect to time; men can and do influence it through technological advances. Theoretically and conceptually, it is possible practically to eliminate the unexpected variations in production due to natural factors, e.g., in an experimental plot or under 'hot house' conditions. Except for irrigation,

however, most other controls are economically impracticable and therefore, in general, physical factors appear as constraints in the production surface.

2.3 In the subsequent sections, the general nature of influence of individual climate factors will be discussed first, to be followed by a brief summary of various attempts at expressing the weather-crop relationship in the form of 'normal law of plant growth': Section-4 will deal with other weather-crop analysis models. Section-5 will deal with the statistical basis for the specification of the weather-crop relationships and the problems that arise in the process. Finally, construction, uses and limitations of the 'weather index' as an alternative, will be discussed in Section-6.

II

2.4 Soil is the 'staging area' for plant growth and at any location its quality is itself an expression of the climate - the basic soil productivity being an expression of the interaction between atmosphere and the climate over a long period.¹ Given the basic productivity and assuming no change in the technology, crop output fluctuates because the relative magnitudes and the occurrence of various climatic factors at different stages of the growth of the plant vary from year to year.

¹ Ray, S.K. : Weather and Reserve Stocks for Foodgrains; EPW, Sept. 1971.

These variations in magnitude and occurrence neither follow a unified pattern nor all of them appear as constraints in the agriculture of a particular region, area or country.

2.5 Weather factors influence yield both directly and indirectly.² The direct influence comes about through the effect on the structural characteristics of the crop, such as stand, number of tillers, leaf area, number of heads per plant, number of kernels per head and weight per kernel of cereals. It may be necessary to go back one or more years, to trace the meteorological causes of certain yield deficiencies. In the case of crops, the weather during the maturing of the seed may conceivably affect its viability and the yielding capacity of next year's crop.

2.6 Weather conditions may exert an indirect effect on yield in several ways. They may influence the rate of growth which in turn may affect the structural characteristics of the crop. This influence may itself be direct or indirect: a retardation of the growth process appears to make for larger kernels in certain cereal varieties; but it may also make it more likely that the crop is overtaken by drought in the critical stage of heading. Weather conditions may influence crop yields by favouring or checking the development of diseases and parasites, of weeds, etc.. They may indirectly affect the average yield by causing variations in acreage too.

² Sanderson, Fred H. : Methods of Crop Forecasting; Harvard Univ. Press, Cambridge, 1954, (pp. 181-187).

2.7 Climatic influences on plant growth can be reduced to three basic elements:³ light, temperature and moisture. Light is essential to the plant because of its importance in the process of sugar formation known as photosynthesis. The sugar which is used to build up the tissues and organs of the plant is formed in the leaves; the rate of growth is therefore also dependent on the leaf area. In practice, the light available to the crops is so abundant that this factor is often ignored in weather-yield studies.

2.8 Unlike moisture, heat or temperature is not used directly by the plant; but is a necessary condition for growth. Living plant thrives best at an optimum temperature of about 30°C to 35°C.⁴ Below a certain temperature, all growth ceases. Extreme temperatures may affect yield directly by injuring the plant, or indirectly by retarding or hastening the growth, and by affecting the water-balance of the plant by evaporation.

2.9 Water-balance, the third factor of vital importance for the plant throughout its life-time, comes from rain or water stored during rains. During sowing time the surface layers of soil should have enough moisture for germination. The period of vegetative growth requires water most - but, that again ought to be punctuated by clear spells and sunshine for optimum growth. A drought at this stage may result in the

3 Sanderson, Fred H. : Op.cit.

4 Ramdas, L.A. : Fundamental Facts of Crop Growth in relation to Environment; JISAS, Vol. 22, Dec. 1970.

plant wilting or dying, whereas a timely rain or irrigation may result in a bumper yield. Similarly, too much of water results in water-logging and stiffling of root-zones. Thus, it is not the total rainfall, but its distribution during the life-time of the plant that is important. To maintain its water balance, the plant must replace the moisture lost by evaporation by a corresponding intake of moisture from the soil. This balance may be disturbed (a) by lack of moisture or (b) by excessive transpiration by high temperatures, excessive dryness of the atmosphere, or wind. The rate of evapotranspiration in certain instances is of equal importance in controlling the water-balance of the plant as the soil moisture. Moisture available for the absorption by the plant not only depends upon the moisture-content of the soil, but also on the composition and physical condition of the soil, characteristics of the variety of the crop, the stage of development of the roots of the plant, and so on.⁵

2.10 Precipitation may have a direct, mechanical influence upon the yield in addition to the effect on the moisture-supply; for instance, through injuring the flowers or by interfering with fertilisation or by washing out nitrates from the soil. The same holds true for other meteorological factors such as high wind, hail or frost. Moreover, weather conditions are, more often than not, responsible for plant diseases and insect damages and growth of weeds.

2.11 However, the effect of a meteorological factor does not only depend upon its total quantum; rather there is a

5 Sanderson, Fred H. : Op.cit.

direct relation between requirements and the rate of growth of the plant. When the rate of growth reaches a maximum, the plant's requirements with respect to moisture, nutrients, etc., would reach a maximum too. The requirements of plants at the different stages of growth are different. These are called the 'critical stages' such as the stages of germination, vegetation and reproduction; and the effect of a combination of weather conditions is dependent upon the time of its occurrence. Besides, the responses of different plants or varieties to identical weather conditions may be quite different. In studies of weather-yield relationships for a given crop, it must be assumed that, other things being equal, the plant reacts in a definite and constant way to a given weather factor.

2.12 Specification and quantification of the nature of influence of the individual climate-factors on crops has a technological as well as a statistical basis. Most of the weather-crop hypotheses are based on trial and error, without embodying well-substantiated theories of causation of yield. Such purely empirical methods might be entirely admissible if checked at every stage by tests of significance, and can even give fairly reliable forecasting formulae. But they do not take advantage of the insight which can be obtained by deductive reasoning. Progress will be more rapid if the search for forecasting formulae goes hand in hand with efforts to analyse

the biological significance of the relationships found. The analysis of the influence of successive causal factors on the actual sequence of development of the plant may suggest sources of yield-variation previously ignored. The causation of yield can be understood only when the components of yield are analysed. For instance, the yield per acre of cereals, is the product of the number of plants per acre, the number of heads per plant, the number of kernels per head and the average weight per kernel. Each of these characteristics may respond differently to a given weather factor. If the weather conditions are studied in relation to each of these components of yield per acre, it is likely that higher correlation would be found than if final yield is used alone. Moreover, the plant characteristics themselves are related to each other; they are part of a complex balance. Some characteristics are compensatory; others show a positive correlation with each other and with final yield.⁶

III

2.13 Very little is known about the true relationship of weather factors to plant characteristics and yield, and about the way in which weather factors combine to influence growth and yield.⁷ It is believed by some that the effect of all environmental factors on yield is subject to decreasing

⁶ & ⁷ Sanderson, Fred H. : Op. cit. The whole of Section III, on the discussion on the 'normal law of plant growth', is based on it. (pp. 198-201).

returns, - with the line of relationship approaching the optimum asymptotically. Others limit this 'Law' of growth of the plant with respect to its environment to 'growth factors' which are used directly by the plant, such as light, water, nutrients, etc.. Still others believe that some or all factors will injure the plant if applied in excessive quantities. With regard to inter-relationship between 'growth factors', however, there is considerable evidence that they are not simply additive - the same weather condition accompanied by others might become beneficial whereas it could be injurious for the plant taken alone or with still others.

2.14 Considerable attention has been paid in weather-crop research to what has been called the 'normal law of plant growth', that is, the law according to which the living substance is formed when all factors are kept constant. If the 'normal' meteorological requirements of a plant is known, the response of the plant to variations in one or more of these factors could be determined at every stage of the growth-cycle; abnormalities of growth caused by meteorological factors could then be analysed and compared to final yields.

2.15 Most of the various efforts of expressing the empirical knowledge of weather-crop relationship are confined to a mathematical description of plant growth over time - they are not concerned with explaining the causes of plant growth, or the causes of deviations from normal growth. Curves of various

types have been suggested to represent the growth law. Most common is the logistic curve :

$$Y = \frac{A}{1 + e^{a + bt}}$$

where $t \rightarrow$ time and $A \rightarrow$ final yield of dry-matter (for $t = \infty$). There have been variations of this; but a more general mathematical hypothesis of plant-growth which takes into account the varying impact of environmental factors on plant-growth and yield was formulated by Mitscherlich and Baule. Mitscherlich's 'effect law of growth factors' states on the basis of some experimental evidence that the effect of any 'growth factor' - which is defined as nutrient or meteorological factor - on yield can always be represented by an exponential curve such as :

$$Y = A (A - e^{-cx})$$

where 'Y' is the yield; 'A' is the maximum yield obtainable with growth factor 'X' present in unlimited quantity; and 'c' is a constant representing the effect of growth factor 'x' on yield. Hence,

$$dy = c(A - Y_0) dx,$$

where Y_0 is the initial yield obtained before the increase in 'x' takes place. Where several 'growth factors' are considered simultaneously, the following relationship is suggested to be used -

$$Y(1, \dots, n) = A(1, \dots, n)(1-e^{-c_1x_1})(1-e^{-c_2x_2}) \\ \dots\dots\dots (1-e^{-c_4x_4})$$

Baule suggested that the growth formula should, in addition, take account of the fact that yield is also a function of time since the growth process cannot be accelerated beyond a certain point at each step of the growth cycle, even if unlimited or optimum quantities of all meteorological and nutrient factors are available. Hence, yield (dry-weight) is determined as a continuous function in time of growth factors, with time itself as an additional limiting factor during the growth cycle of the plant :

$$Y(x'(t), t) = \int_0^t Y[x'_1(t), x'_2(t) \dots] mct^{m-1} e^{-ct^m} .dt$$

where 'x' are growth factors measured in standardised doses, and 'm' is a constant in the function representing the influence of the time factor :

$$Y(t) = 1 - e^{-ct^m}$$

The function $Y[x'(t), t]$ gives the yield at any moment 't' of the life cycle as well as the final yield ($t = \infty$).

2.16 "The Mitscherlich - Baule hypothesis appears to be the first attempt at rationalising the existing experimental evidence on weather-crop and fertilizer-crop relations into one comprehensive mathematical system. While the particular mathematical form of the proposed 'growth law' has been

questioned, it indicates the aim for which quantitative biology must strive.⁸ However, the weather crop studies discussed below do not take into account this 'law'; rather other models for weather-crop analysis have been constructed in recent times, two of which are discussed in the following section.

IV

2.17 Weather-crop analysis models in recent times have constructed as the product of two or more factors, each representing the functional relationship between a particular plant response (e.g. yield) and the variations in selected variables at different plant-development phases.⁹ The overall effects as expressed by the numerical values of the factors modify each other but are not additive as in the case of a multivariate linear regression equation. Such models do not require a formulated hypothesis of the influence of the environmental factors on the plant; and are practical research tools for the analysis of crop responses to weather and climate variations when only climatological data are available. Conventional statistical procedures are used in such models to evaluate the coefficients relating crop-responses to climatological or derived agrometeorological data. A typical model is Baier's

⁸ Sanderson, Fred H., Op.cit., pp. 201.

⁹ Summarised in 'Crop-Weather Models and Their Use in Yield Assessments'; by Wolfgang Baier, WMO-Technical Note No. 151, 1977.

model,¹⁰ where the primary objective is to analyse the daily contribution of upto three selected agrometeorological variables to the final or seasonal yield, although other crop responses such as vegetative growth or reproductive development are also considered. The crop-response to the input-variables changes gradually during the life cycle of annual crops as a function of bio-meteorological time. With the response characteristic unknown and not predetermined, it is assumed that a 4th degree polynomial, with biometeorological time as independent term, is adequate for fitting the daily weighing factors associated with the daily contribution of each variable to the final yield. The three agrometeorological variables chosen are solar energy, temperature, and soil moisture (or evapotranspiration), which modify each other on any particular day during the life-cycle of a crop and produce a positive or negative effect on the yield. The basic equation of the model is :

$$Y = \sum_{t=0}^M V_1 \times V_2 \times V_3$$

where $Y \Rightarrow$ the dependent variable like final observed crop-yield;
 $V_1, V_2, V_3 \Rightarrow$ the functions of the selected independent agrometeorological variables. Each V-function is of the general form :

$$V_j = (u_1t + u_2t^2 + u_3t^3 + u_4t^4) + (u_5t + u_6t^2 + u_7t^3 + u_8t^4) x_j \\ + (u_9t + u_{10}t^2 + u_{11}t^3 + u_{12}t^4) x_j^2$$

¹⁰ Detailed in 'Crop Weather Analysis Model-I'; International Journal of Biometeorology, Vol.17, No.4 (1973) - Inaccessible.

where $u_1, u_2 \dots u_{12}$ are coefficients which are evaluated for each V_j in an iterative regressive analysis in which the intercept has been suppressed, and x_j in V_j represents a specific variable which has been selected for analysis in a particular run.¹¹

2.18 Another model, known as the Factorial Yield Weather Model (FYNM)¹² has been proposed by Robertson in 1974 which involves ~~an~~ summation of the products of several quadratic functions for various weather elements, such as precipitation, maximum and minimum temperatures, global radiation and evaporation. Time is used as an indicator of advancing technology and one function contains a term for the antecedant crop condition :

$$\hat{Y}_t = V_1(\hat{Y}_{t-1}, P_1) \times V_2(T_1)t \times V_3(T_2)t \times V_4(Q)t$$

where $\hat{Y}_t \Rightarrow$ yield estimated at time 't', of a given crop stage

$P_1 \Rightarrow$ Total precipitation between stages t and t-1

$T_1 \Rightarrow$ Average of the daily maximum temperature during the period between stages t and t-1.

$T_2 \Rightarrow$ Average of the daily minimum temperature during the period between stages t and t-1.

$Q \Rightarrow$ Average daily global radiation during the period between stages t and t-1;

and functions V_1, V_2 , etc., are of the form :

11 It has not been possible to lay hands on the few applications of this model. Baier's model claims to have given the closest estimates (C.D.=0.77) of wheat yields as obtained from experiments conducted from 1953-62 at eight Canada Deptt. of Agricultural Research establishments.

12 Baier, W.: Op.cit.

$$\begin{aligned}
 V_1(\hat{Y}_{t-1}, P_t) &= b_0 + b_1 \hat{Y}_{t-1} + b_2 P_t \\
 V_2(T_1) &= p_0 + p_1 T_1 + p_2 T_1^2 \\
 V_3(T_2) &= q_0 + q_1 T_2 + q_2 T_2^2 \\
 V_4(Q) &= r_0 + r_1 Q + r_2 Q^2
 \end{aligned}$$

where b, p, q and r are regression co-efficients to be evaluated for each crop period.

2.19 This model strives for assessing, at any time during the crop-developmental period, the influence of past and current weather on future expected yield. Both the models can be used for both analysis of crop-weather data and prediction of yields. But there are not many replication of this exercise for different crops in different situation.

V

2.20 In practically all weather-crop studies, the greatest handicap has been the inadequacy of the statistical data which serve to describe the crop's environment. It is of particular importance in the more frequently adopted empirical-statistical approaches where one or several variables are related to crop-responses such as yield. The statistical specification of the agrometeorological variables is often difficult, and has to rely upon the underlying agronomic research before including them in the model, because the statistical approach does not lead to an explanation of the cause and effect relationship.

The co-efficients in such models and the validity of the estimates depend to a large extent on the design of the model as well as the representativeness of the input data.¹³ More often variables are tested as to whether or not they contribute to a high value of R^2 (the coefficient of determination) - those which do are selected, and at this stage, agronomic research is sought to substantiate the original selection.¹⁴

2.21 The effect of meteorological variables on crop-responses may be entirely different depending upon the area under consideration. In the higher latitudes, for instance, temperature and sunshine are serious limiting factors besides soil moisture, and hence, the emphasis in their studies on thermo-periodism and photo-periodism.¹⁵ In India, however, temperature and sunshine do not act as limiting factors for the crops which are commonly grown.¹⁶ Similarly, precipitation by itself is perhaps the most important growth factor; but the same precipitation combined with high temperature, low humidity and low

¹³ Baier, W. : *Op. cit.*

¹⁴ Shaw, Lawrence H. : The Effect of Weather on Agricultural Output: A Look at Methodology; JFE, Vol. 46, Feb. 1964.

¹⁵ Report of the National Commission on Agriculture; Part IV, pp. 24-25.

¹⁶ Ray, S.K. : *Op. cit.* An analysis of data pertaining to about 50 meteorological stations of India, published in the World Weather records, indicated that month-wise variations in temperature over the years (30 to 90 years) were not significant, excepting in some hilly areas - so also some factors like snowfall, intensity of light, etc.. "Seven to Nine hours of sunshine in clear seasons and 3-5 hours of sunshine during the South-west monsoon period per day, on an average, is expected over a large part of the country". (RNCA, *Op. cit.*, pp. 24).

soil moisture has different effects than when combined with low temperature, high humidity and high soil moisture. The relationships and inter-relationships are also complicated.

2.22 Many statistical problems arise in the process of collection and maintenance of meteorological and phenological records to be later used in the ultimate analyses. One is the specification of an appropriate functional relationship between the meteorological factor such as precipitation or temperature with the crop-response such as yield. From general observation it is known that too much as well as too little of rain can be harmful, or for that matter, excessively warm or excessively cool weather retards plant growth. Hence, a bell-shaped curve is a reasonable hypothesis. For simplification, it has usually been assumed that the relevant range is only the rising part of the curve and the relationship has been approximated by a straight-line. But it is quite possible that in reality the declining part is reached.¹⁷ A solution to the problem is to use a quadratic function - but unfortunately in all time series analysis the number of observations is limited to around 30 or even less; and quadratic functions in a multivariate regression model double the number of independent variables used, thus reducing drastically the available degrees of freedom. Moreover, once a general type of functional relationship is decided, there is no assurance that the general function will be equally appropriate to the

17 Shaw, Lawrence H. : Op.cit.

different kinds of meteorological variables. Similarly, the relationships may vary for different parts of the season, different crops, different areas of the country.¹⁸

2.23 Assumption of independence between weather and technology is another serious problem. Drought-resistant varieties, limited tillage combined with more effective weed control, etc., have done much to offset the adverse effects of unfavourable weather, e.g., a deficiency in rainfall in 1930 may have cut crop yield by 25 per cent, but in 1980, it may cut yields by 10 per cent. So, it is reasonable to hypothesize that technology and weather are not independent of each other, rather there is an interaction between them which introduces a bias in the estimates such that in the years near the present, the yield-effect of meteorological factors is overestimated and vice versa.¹⁹

2.24 It is difficult to use unaggregated meteorological data in a weather-crop model for an area or a country; and they, too, do not give accurate results. Therefore, aggregation (as averages) is usually done. But this again gives rise to problems because the relationship between yield and meteorological factors is not monotonic but more like in a bell-shaped curve. Assuming the optimum yield under such functional relation is achieved at 4 units of a meteorological

18 } Shaw, Lawrence H. : Op.cit.

19 }

factor, and 3 units yield approximately the same as 5 units (the two lying on two sides of the bell), a geographical aggregation might lead to serious error, because if a unit deviation in the meteorological factor causes a fall of 25 per cent in the yield in two divisions of a state, the aggregate would still show the optimum, whereas the yield could, in fact, be reduced by 25 per cent.

2.25 Besides these, there are other problems such as the employment of different weighting schemes used to construct the yield average and the meteorological averages. A related problem is of aggregating meteorological data over time - a monthly average may be misleading if composed of 25 dry days and 5 days of torrential downpour. The solution, of course, is to increase the number of meteorological variables by using averages for shorter periods. But, this would multiply the number of independent variables, thereby limiting the available degrees of freedom. Another problem is associated with the definition of 'time'; for the plant time is relative to phenological development whereas meteorological time is usually calendar-time.²⁰

VI

2.26 The objective of the multiple regression studies has been to estimate an equation which will measure the yield

20 Shaw, Lawrence H. : Op.cit.
Ray, S.K. : Op.cit.

effects of weather factors in any given year. Interest is usually in combining all weather factors rather than isolating weather variables in the equation; because all the regression coefficients are rarely significant. Therefore, there have been many suggestions of composite indexes of broad meaning, especially to classify climates and draw their boundaries.²¹ The proposition is "that what can be done geographically to distinguish dry climates from moist climates can be transposed historically over years, and that an index which distinguishes between excess or insufficient moisture from one location to another in a given year should also measure effectively weather variations in a given area from year to year and provide immediately an operational tool in production analysis."²²

2.27 Thornthwaite emphasized the importance of evaporation as a climatic element, called the combined evaporation from the soil surface and transpiration from plants as 'evapotranspiration' which represents the reverse of precipitation. Evapotranspiration rises to a maximum in a way that depends on environmental climate. This maximum is called the 'potential evapotranspiration'. In his research, Thornthwaite found that the rate of evapotranspiration depends on four independent things : climate, soil moisture supply, plant cover, and land management; and from further experimental observations generalised the Van't

21 Oury, Bernard: A Production Model for Wheat & Foodgrains in France; The major portion of this section is based on Oury's summarisation of composite indexes. (pp. 24-29)

22 Oury, Bernard,: Op.cit., pp. 24.

Hoff law of physics to give a moisture ratio that expresses relative humidity or aridity during a given period in a given location as follows :

$$m = \frac{p - e}{e} = \frac{p}{e} - 1$$

where $m \Rightarrow$ the moisture ratio; $p \Rightarrow$ precipitation and $e \Rightarrow$ potential evapotranspiration. Positive values of the ratio imply that the precipitation is excessive, negative values that ~~ix~~ it is deficient.

2.28 Recognising that temperature is the major factor for evaporation, various researchers have suggested simpler formulae substituting temperature for evaporation. Lang's rain factor expressed as a ratio : $I = P/T$ indicates that effectiveness of rain varies directly with precipitation (P) and inversely with temperature (T). De Martonne suggested a refinement of Lang's formula by adding the constant 10 to the temperature to avoid negative values : $I = P/T+10$.

2.29 Koppen suggested three other modifications for delienating the dry climates, and possibly dry periods :

$$I = \frac{8P}{5T + 120}, \quad I = \frac{2P}{T + 33}, \quad I = \frac{P}{T + 7}$$

Angstrom suggested a modification of De Martonne's index of aridity after he found that index of aridity was proportionate to the duration of precipitation which was in turn directly proportionate to the amount of precipitation and inversely

proportionate to an exponential function of temperature :

$$I = P/1.07^T.$$

Oury suggested that a weather index or aridity index could be computed with a comparable scale using monthly precipitation and average monthly temperature; and a general formula for any number of cumulated months would be

$$I = \frac{1}{n} \sum_{i=1}^n (P_i) \times 12 / \frac{1}{n} \sum_{i=1}^n (T_i) + 10$$

2.30 Knetsch²³ used drought index as an explanatory variable in his yield equations. He defined a drought day to occur when the available moisture in the soil reaches a point of zero-availability as measured by the differences between daily precipitation and evapotranspiration. A weighted average of the drought day intensity during a crop season, with the weights based on the correlation between drought occurrence and yield, was used to calculate the drought index.

2.31 Hypothesising that meteorological variables are a weighted function of time, Ram Dayal²⁴ and John P. Dell have separately suggested a scheme of collapsing the weekly or fortnightly observations on rainfall and temperature into a single variable, if the relationship is assumed to be linear, or a few composite variables when non-linear, which can be

23 Dubey, J.B. : Weather Indexes: A review of the methods of Constructing Indexes of the Effects of Weather on Crops; JISAS, XXII, 1970 (Dec.)

24 Ram Dayal : Impact of rainfall on Crop Yield and Acreage; IJAE, XX, 3, 65.

used as explanatory variables in yield operations.

2.32 However, Stalling's work was "apparently the first which actually provided indexes of the total influence of weather upon the major crops in a form that could be used in aggregative production econometric model building."²⁵ Others who have also contributed in this direction are Glenn L. Johnson, Dale E. Hathaway, Lawrance H. Shaw and Louis M. Thompson. It is assumed that if time series of yields for particular crops can be obtained from experimental plots in the areas where these crops are grown and where as many variables as possible have been held constant, the remaining variation in yields, after any trends have been removed, can be considered due mainly to weather. Any other variation not accounted for is assumed to be randomly and normally distributed with an expected value of zero. A weather index is then computed as the ratio of actual yields to a fitted trend.²⁶

2.33 A weather index, thus computed, can be used to measure the technological change indirectly by deflating for the influence of weather-variations in the same way a price-index is used. No assumption with regard to the pattern of technological change is necessary to be made and it can be applied to different crops, different areas of the country and

25 Oury, Bernard : Op.cit., pp. 24.

26 Stallings, James L. : A Measure of the Influence of Weather on Crop Production; JFE, Dec., 1961.

different degrees of aggregation. The weather index approach avoids not only the question of exact cause-effect relationship, but is also devoid of the difficulties associated with the statistical attempts at measuring the influence of weather and yet provides most of the answers.²⁷ Aggregation over time is not a problem here because the final variation in experimental yield is used as the measure of the influence of weather. Weather is measured as the net effect of all meteorological factors on yield; hence, the timing of rainfall or temperature is not a stumbling block. The growing of the crop in the experimental plot would be done by making all necessary and possible adjustments to changing rainfall and temperature, etc.. In addition, fully comparable weighting system is used while computing the weather index for the district or state or country, if there are such experimental plots in sufficient numbers in the different agro-climatic areas of a district and a state.

2.34 One limitation of this way of deriving an overall weather index is that it can be useful in explaining factors affecting variation in yield in the past; but it cannot be of much use in forecasting yield in the future. And the other more serious one is that the data sources limit such index to those areas for which an adequate 'sample' of yield series is available. A small sample-size may lead to an overestimation of the effects of weather at highly aggregative levels, since variation in crop-yield per acre is generally an inverse function of the size of area under production.

27 Shaw, Lawrence H. : Op.cit.

CHAPTER THREE

WEATHER-CROP STUDIES ABROAD

I

3.1 As was discussed in Chapter Two, hypotheses regarding the response of plants to weather factors may be tested by experimental or by statistical methods. In the experimental method, weather factors as well as other factors are, at least in principle, subject to rigorous control. Simulation provides an insight into weather-crop relationships, explains why some factors are more important for yield than others, suggests factors likely to have statistical significance and provides the basis for new experiments on processes which are apparently important but not yet sufficiently understood.¹ But such experiments inside the laboratory or green-house or field require elaborate equipments and a highly technical staff for supervision and analysis; all of this is very expensive and uneconomical, and suffers from other limitations because of which statistical methods are often taken recourse to. It is apparently impossible to reproduce exactly the various weather conditions and the conditions in the field. Moreover, the number of factors which ought to be studied independently become only too large, whereas in the statistical method the inter-correlation between the effects of indivi-

1 Baier, Wolfgang : Crop-Weather Models and Their Use in Yield Assessment; WMO Technical Note, 151, 1977.

dual weather factors makes it possible to treat such a complex of variables as one variable. There, it is the task of the statistician to isolate, as far as possible, the influence of individual weather factors, while holding the other factors 'constant' at specified levels by means of statistical analysis. The simulation approach, as a practical research tool to investigate more thoroughly specific plant-environment processes, may not altogether replace the statistical approach; but certainly be a complementary to it.

3.2 The present chapter reviews the statistical research done abroad, in crop-weather relations in three stages, since the replication and findings of the experimental researches carried out elsewhere are inaccessible. Section II deals with some of the early studies in this direction consisting of simple correlation analysis, to be followed by the refined method of 'Regression Integrals' as suggested by Fisher, in Section III. Section IV deals with a few of the recent studies using regression-techniques to forecast the yield.

II

3.3 Since there is a logical cause and effect relationship between weather and crop yields, direct use of weather as a means of forecasting crop-yields has been a challenge of long-standing. Some of the earliest statistical enquiries

into these relations consisted of simple correlation studies, where the final crop-yield was charted against a single variable, usually monthly or total rainfall during a growing season; or temperature during supposedly critical months. The equation of the form $Y = a + bX$, was used to estimate such statistical constants as the coefficient of correlation and standard error of the estimates.

3.4 R.H. Hooker,² in 1907, was the first to apply formal correlation methods to the study of weather-crop relationship as a response to the hypothesis of Sir W. Napier Shaw that the amount of precipitation received in the fall, about seeding time, seemed to exert a considerable negative influence on the yield of winter wheat in Eastern England. Hooker's study, which served as a model for many subsequent investigations, involved the calculation of some 700 correlation coefficients,³ based on a period of 20 years, between

2 Hooker, R.H. : "Correlation of Weather and Crops", Journal of the Royal Statistical Society, No. 70, March, 1907.

3 The simple correlation coefficient, between the yield and (1) the rainfall, and (2) the temperature is given as -

$$r = \frac{\sum(xy)}{\sqrt{n \sigma_1 \sigma_2}}$$

Partial or net correlation coefficients are computed as

$$r_{12} = \frac{r_{12} - r_{13} \cdot r_{23}}{\sqrt{(1-r_{13}^2)(1-r_{23}^2)}}, \text{ between yield and rainfall when}$$

the effect of temperature is approximately eliminated; and

$$r_{13} = \frac{r_{13} - r_{12} \cdot r_{23}}{\sqrt{(1-r_{12}^2)(1-r_{23}^2)}}, \text{ between yield and temperature}$$

when the effect of rainfall is approximately eliminated.

the yields of ten crops and rainfall and temperature data for successive overlapping eight-week periods separately. The partial correlation coefficients between yield and rainfall, after elimination of temperature effects, and between yields and temperature, after elimination of rainfall effects, as well as the multiple correlation coefficients between yield, rainfall and temperature, are also shown for each period. Among other conclusions drawn from this analysis, it was found that absence of rain in September and October was more important to wheat crop than rain or temperature at any other period of the year, which was a strong evidence in favour of Sir Napier Shaw. The combined effect of rain and temperature in winter seemed at least as great as the autumn rainfall alone. With regard to temperature, Hooker concluded that wheat likes a mild winter, a cold spring and a dry July. All these conclusions were drawn from a comparative study of the successive correlation coefficients and the highest coefficient has been regarded as exercising the most influence. Further, the choice of 8-week successive periods is not only arbitrary, but also unrepresentative for, the most critical period for wheat is shorter; besides raising multicollinearity problems in a multiple regression analysis.

3.5 In 1910, A. Walter⁴ investigated the effect of temperature and 'effective rainfall' on the yield of cane sugar in

⁴ Walter, A. : The Sugar Industry of Mauritius, London, 1910. - Inaccessible. Reviewed by Fred H. Sanderson, Op.cit., pp. 213-214.

Mauritius (during 1892-1905) where he defined 'effective rainfall' by the expression, $I = Rt$; where 'R' is the total rainfall and 't', the percentage of rainy days, thus weighting any amount of rainfall by the number of days during which it fell. Walter then computes the partial regression coefficients and draws his conclusions which were of questionable significance. This was probably because he determined 6 constants from only 10 observations. Yet, Walter's work was considered as a genius piece, remarkable for its scope.

3.6 H.L. Moore⁵ is one of the most outstanding early advocates of the methods of correlation as applied to crop and price forecasting. In his 'Economic Cycles: Their Law and Cause', Moore studied the critical periods with respect to rainfall, of various crops in the State of Illinois. He also gave formulae, based on weather records, to predict cotton yields which claimed greater accuracy than the official forecasts at a much later date. Henry A. Wallace⁶ is another of the firsts to make use of multiple regression methods to predict crop-yields from selected weather factors.⁷ The United

5 Moore, H.L. : 'Economic Cycles : Their Law and Cause' (New York, 1914). - Inaccessible.

6 Wallace, Henry A. : 'Mathematical Enquiry into the Effect of Weather on Corn Yields in the Eight Corn Belt States'; USDA, Monthly Weather Review (1920). - Inaccessible.

7 Review from Fred H. Sanderson, Op.cit., pp. 214-215.

States Weather Bureau, too, became interested in the study of weather-crop relationships; and a Division of Agricultural Meteorology was created in 1916 under the leadership of J. Warren Smith, which undertook a number of investigations of the factors determining the yield of cereals crops and cotton. The idea of investigating systematically the effect of the seasonal distribution of weather elements on crop-yields was later taken up, with more refined methods, by R.A. Fisher.⁸

III

3.7 Fisher, guided by the consideration that in studying the influence of a meteorological factor, not only its total amount during a certain period be taken into account, but also the manner in which it is distributed over the period be noted, developed his technique of 'regression integrals'. In its general form it is as follows⁹:

3.8 Let M_1, M_2, \dots, M_k be 'k' meteorological factors influencing the yield of the crop 'y'. Let 'q' be the subdivision of the year for each of which records of the meteorological factors are available. The multiple linear regression equation of the yield of the crop upon the 'k'

⁸ Fisher, R.A. : 'The Influence of Rainfall on the Yield of Wheat at Rothamsted'; Philosophical Transactions of the Royal Society of London, Series B, 213 (1924).

⁹ The entire formulation is borrowed from K.R. Nair and P. Bose : 'Influence of Humidity and Temperature on the Yield of Cotton'; Sankhya, Vol. 7, part-2, Nov. 1945.

meteorological factors is written as -

$$Y = C + \sum_{n=1}^q a_{1n} m_{1n} + \sum_{n=1}^q a_{2n} m_{2n} + \dots + \sum_{n=1}^q a_{kn} m_{kn} \dots (1)$$

where $m_{11}, m_{12}, \dots, m_{1q}, m_{21}, m_{22}, \dots, m_{2q}, m_{k1}, m_{k2}, \dots$
 \dots, m_{kq} are the measurements of the meteorological factors
 in the different intervals of time. If the subdivisions
 of time were made infinitely small, we should replace the
 linear regression function by a regression integral of the
 form :

$$Y = C + \int_0^T a_1 m_1 dt + \int_0^T a_2 m_2 dt + \dots + \int_0^T a_k m_k dt \dots (2)$$

where $m_k dt$ in general is the effect of the meteorological
 factor in the element of time dt . The integral is taken
 over the whole period.

3.9 If $T_0, T_1, T_2, \dots, T_n$ be a series of orthogonal
 functions of time such that -

$$\int_0^T T_r T_s dt = 0 \quad (r \neq s), \quad \int_0^T T_r^2 dt = 1, \text{ then,}$$

we may represent the series of values of each of the meteorological factors as a time series using the following orthogonal polynomials.

$$\left. \begin{aligned} m_1 &= e_{10} T_0 + e_{11} T_1 + e_{12} T_2 + \dots + e_{1n} T_n \\ m_2 &= e_{20} T_0 + e_{21} T_1 + e_{22} T_2 + \dots + e_{2n} T_n \\ m_k &= e_{k0} T_0 + e_{k1} T_1 + e_{k2} T_2 + \dots + e_{kn} T_n \end{aligned} \right\} \dots (3)$$

$$\text{where } \ell_{is} = \int_0^T m_1 T_s \cdot dt.$$

The regression values $a_{i1}, a_{i2}, \dots, a_{in}$, for the meteorological factors in (1) may be expected to lie on a continuous time curve so that we may express the regression function in (2) in the form —

$$\left. \begin{aligned} a_1 &= \mathcal{L}_{10} T_0 + \mathcal{L}_{11} T_1 + \mathcal{L}_{12} T_2 + \dots \\ a_2 &= \mathcal{L}_{20} T_0 + \mathcal{L}_{21} T_1 + \mathcal{L}_{22} T_2 + \dots \\ a_k &= \mathcal{L}_{k0} T_0 + \mathcal{L}_{k1} T_1 + \mathcal{L}_{k2} T_2 + \dots \end{aligned} \right\} \dots (4)$$

$$\text{where } \mathcal{L}_{is} = \int_0^T a_i T_s \cdot dt.$$

The degree of polynomials in (3) and (4) should be the same and in practice seldom exceeds 4 or 5. Now, using the relations (3) and (4), the relation (2) stands as

$$\begin{aligned} Y &= C + (\ell_{10} \mathcal{L}_{10} + \ell_{11} \mathcal{L}_{11} + \dots + \ell_{1n} \mathcal{L}_{1n}) \\ &+ (\ell_{20} \mathcal{L}_{20} + \ell_{21} \mathcal{L}_{21} + \dots + \ell_{2n} \mathcal{L}_{2n}) + \dots \\ &+ (\ell_{k0} \mathcal{L}_{k0} + \ell_{k1} \mathcal{L}_{k1} + \dots + \ell_{kn} \mathcal{L}_{kn}) \dots (5) \end{aligned}$$

Now, the values $\ell_{10}, \ell_{11}, \dots, \ell_{k0}, \ell_{k1}, \dots$ may be obtained for each year by fitting orthogonal polynomials for each meteorological factor, then correlating this series with the yield of the crop for several years, we can get values of \mathcal{L}_{is} ($i = 1$ to k ; $s = 1$ to n) as partial regression coefficients using relation (5). By substituting these

values in (4) we get values of a_1, a_2, \dots, a_k which will give the effect of fluctuations in each meteorological variable at any point of time in the season on the yield of the crop at the end of the season.¹⁰

3.10 Fisher's original study concerns the yields of wheat on 13 plots at the Rothamsted Experimental Station, under continuously uniform treatment since 1852, thus providing an exceptionally long, homogeneous series. He takes data for 60 years and fits orthogonal polynomials of the fifth degree to the sixty annual sequences of six-day totals of rainfall. The effect of the amount and distribution of rainfall on the yield of wheat was found to vary considerably, depending on the manurial treatment. The average effect of rainfall appeared to be harmful in all the plots - winter rainfall being particularly damaging. The minimum damage was in May.

3.11 Tippett studied the net effect of the amount and distribution of sunshine on the yield of wheat on one of the 13 plots studied by Fisher in the same way; and found that sunshine was beneficial throughout the year. Similar studies have been carried out by Pallesen and Laude, Davis and Pallesen, Davis and Harrell with regard to different meteo-

¹⁰ For the sake of simplification of the computations, the orthogonal and normalised polynomials in the model, may be replaced by the polynomials ξ' . The values of ξ' have been tabulated by Fisher and Yates. The procedure of using tabulated values of ξ' is amplified in 'Methods of Statistical Analysis' by Cyril H. Goulden (John Wiley and Sons, Inc., N.Y.)

rological factors at different places. There have also been some Indian studies adopting this method, which will be discussed in Chapter Four.

3.12 Although Fisher's method possesses an elegance and a conciseness in representing the average effect of a weather factor on yield, it, too, has limitations. It does not take account of joint effects between successive precipitations. It is assumed that the effect of precipitation at any time is independent of the amount of precipitation at any other time, and hence, the additive relationships. Moreover, the use of calendar periods calls for the criticism that Fisher's contention may be justified for a given crop-phase, but may not hold good during the transition of the crop from one phytophase to another such as vegetative development to reproductive phase. There are critical phases, such as 'crown-root initiation' and 'tillering', lasting for two or three weeks and with their own special weather optima. Lastly, it requires a very long series of data for, it reduces the degrees of freedom considerably.¹¹

IV

3.13 An abundant amount of literature grew up in the 1920's following Henry A. Wallace. The 'Bean Method' of graphic multiple correlation, a logical extension of the simple correlation dot-chart procedure, made curvilinear relations

¹¹ Sreenivasan, P.S. : 'Studies in Agricultural Meteorology of Some Field Crops'; Unpublished Ph.D. thesis at Mahatma Phule Krishi Vidyapeeth, Rahuri (1970).

developed with a statistical understanding of the effect of a combination of variables on the yield. Notable among the researchers at the time were J.B. Kincer, W.A. Mattice, B.B. Smith, H.J. Henny and others. Most of the studies used precipitation and soil moisture as the principal explanatory variables and tended to be limited to one crop in one climatic area. Even while the correlations were significant and fairly high, the relationship when used in subsequent years, would not be the same as for the years included for the study, and hence, for purposes of forecasting, they were misleading. This was probably because, working with a 15 or 20 years period data, several weather factors and mostly curvilinear relationships, degrees of freedom were comparatively smaller. Therefore, though the 'direct' procedure in estimating has not been abandoned, the emphasis has shifted to 'indirect' or supplemental weather approach, where considerable use of multiple regression in estimating yield with reported condition and/or yield, precipitation, or indices of weather as variables is made. Thornthwaite, Shaw, Stallings and Palmer, as mentioned in Chapter Two made significant contributions in developing weather-indices in an attempt to incorporate crop production and climatic data in econometric studies.

3.14 Three major sources of variability in yield of grain over a period of years can be identified - (a) Technological change, (b) Meteorological variability, and (c) Random 'noise'. The technological change is reckoned as the most

important source of variability and is often assumed to have increased yields smoothly over time; therefore, years or some other parameter of time are used as an independent variable in the recent regression analyses. Random 'noise' in yield-weather models is a combination of truly random events including those technological and meteorological influences not specifically included in the model, the awareness of which is important especially while evaluating the impact of actual or hypothetical changes in the input variables.

3.15 Richard Perrin used Palmer's drought index for an intensive study of yields of selected crops in the United States and developed yield-weather relationships for corn in Illinois and Iowa, for winter wheat and grain sorghum in Kansas and Nebraska, and for spring wheat in North Dakota. His study used selected combinations from 26 variables for Kansas winter wheat yields and was based on 1946-66 data. His best equation, in terms of R^2 , contained variables for location within State, a variable for time, and fall and spring weather variables, which were based on Palmer index. He obtained an R^2 of 0.82 and a standard deviation of 3.2 bushels per acre, roughly 15 per cent of recent yield levels.¹²

3.16 Bernard Oury's¹³ study of wheat and feedgrain produc-

¹² Perrin, Richard : Analysis and Prediction of Crop Yields for Agricultural Policy Purposes; Unpublished Ph.D. thesis, Iowa State University (Inaccessible; referred to in 'Forecasting Wheat in Turkey', by Arthur Coffing.)

¹³ Oury, Bernard : A Production Model for Wheat and Feedgrains in France; North Holland Publishing Co., Amsterdam, 1966.

tion in France was the first that attempted to use the De Martonne aridity index. The study was based on 1946-61 data, and used weather, technological, and economic variables to develop models for yield, area and production of wheat and feedgrains. He developed two series X_3 to represent weather data : one was a weighted average, weighted by production for 30 stations scattered throughout France; the other was a simple series from the Paris weather station since Paris happens to be the centre of the wheat-growing region in France. When compared, the two series gave very similar results; and therefore, Oury used the simpler series for his prediction models. The equation finally selected for wheat-yield was :

$$\begin{aligned}
 Y_w = & 656.52 - 28.259 X_3 - 9.1632 X_4' \\
 & (145.45) \quad (1.6040) \quad (4.5171) \\
 & + 1066.3 X_{11} + 2.9451 X_{45} \\
 & (2.9861) \quad (8.9833)
 \end{aligned}$$

where Y_w \longrightarrow Average yield of all wheat, kg/hectare;
 X_3 \longrightarrow 'winter effect' weighted for wheat acreage,
in $d^{\circ}C$.
 X_4' \longrightarrow the aridity index average compounded
over 9 months cumulated (Oct. through June)
 X_{11} \longrightarrow 3-year moving average of the price of wheat
deflated by wholesale price index;
and X_{45} \longrightarrow 3-year moving average of nitrogen consumption.

t - values are given in paranthesis, which are significant for all explanatory variables but one, X_3 . Oury obtained an $R^2 = 0.91$ with a standard deviation of 145 kgs. The

final explanatory variables are chosen from among 9 environmental variables, 20 price variables, 10 production variables and 3 technological variables after running a series of regressions. Similar regression analysis was done for his acreage model where, too, he obtains $R^2 = 0.93$ with a standard deviation of 144,000 acres; and production model where $R^2 = 0.91$ and standard deviation = 797,000 tonnes.

3.17 John P. Doll¹⁴, in 1967, used Missouri corn yields to show how a weather index could be constructed. He used 8 weeks of data for 37 Missouri weather stations for the years 1930-63. When the Index was coupled with a variable for technology, where he used a cubic time-trend, it explained 90 per cent of the variations in corn-yields. He suggested that about 66 per cent of the variation could have been explained by weather alone. However, he did not perform any statistical tests since his weather stations were not randomly selected.

3.18 Another study by Arthur Coffing¹⁵ in an attempt to forecast wheat production in Turkey, also makes use of De Martonne index, where the monthly weather data are converted to an aridity index, and then the monthly index into 2- and 3-month cumulative index :

$$I_i = (12P_i)/(T_i + 10)$$

$$I_j = \sum I_i V_i / U$$

¹⁴ Doll, John P. : 'Estimating Weather Indices'; JFE, Vol. 49, No. 1, Feb. 1967.

¹⁵ Coffing, Arthur : Forecasting Wheat Production in Turkey; USDA Economic Research Service, Foreign Agricultural Economic Report, No. 85, 1973.

where I_i \longrightarrow monthly aridity index,
 P_i \longrightarrow monthly precipitation;
 T_i \longrightarrow monthly average temperature,
 I_j \longrightarrow cumulative aridity index;
 V_i \longrightarrow statistical variance of I_i
 and U \longrightarrow the sum of the V_i .

To explain variations in wheat yields, area planted, and production during 1948-68, separate sets of regression runs are made and the final equations were selected. The final equation for wheat-yield was :

$$Y = 883.9 - 2.03 X_5 + 11.15 X_{12} + 0.13 X_{13}$$

(2.93) (4.31) (3.04)

where Y \longrightarrow National Yields in Kg/hectare
 X_5 \longrightarrow Jan-Feb. aridity index for Ankara
 X_{12} \longrightarrow May-June aridity index for Ankara
 X_{13} \longrightarrow Fertilizer consumed in 1,000 metric tonnes.

t - values are given in parantheses. The R^2 obtained was 0.82 with a standard deviation of 104.3. It was found that forecasts based on a set of weather data closely associated with yields in a major component of the total, result in a smaller standard deviation than do forecasts based otherwise.

3.19 Thus, a marked development in phases can be noticed in the quest for an empirical-statistical relationship between the weather and the crop. It started with the simple corre-

lation analysis-studies to be refined into more elaborate and complex analysis in terms of regression-integrals, and finally, the multiple regression techniques are employed with the objective of forecasting for the future. In the latter cases, again, there seems to be a shift from employing weather factors directly as the explanatory variables, to the use of weather-indices instead, which seems to have improved the results at least in terms of the coefficient of determination.

CHAPTER FOUR

WEATHER-CROP STUDIES IN INDIA

I

4.1 Weather-crop relationships have also fascinated Indian authors for long.¹ Though a few studies have been done by agricultural scientists (notable being Harold Mann,² Kalamkar and Satakopan,³ Kanitkar,⁴ Kaul and Sidhu⁵), India Meteorological Department has been the main centre of research for such studies. Most of these studies are of empirical-statistical nature employing the methods of correlation and regression, and endeavouring to develop techniques for quantitative crop-yield forecasts on the basis of 'long series of past crop yield data and meteorological parameters'.⁶

1 Indian studies can be traced as far back as 1910 to S.M. Jacob, 'On the Correlation of Areas of Matured Crops and the Rainfall and Certain Allied Problems in Agriculture and Meteorology'; Memoirs of the Asiatic Society of Bengal (1910).

2 Mann, Harold H. : Rainfall and Famine - A Study of Rainfall in the Bombay Deccan; ISAE, Bombay, 1955.

3 Kalamkar, R.J. and Satakopan, V. : Influence of Rainfall Distribution on the Cotton Yields at Government Experimental Farms at Akola and Jalgaon, IJAS, 1940.

4 Kanitkar, N.V. : Dry-farming in India; ICAR, New Delhi, 1960.

5 Kaul, J.L. and Sidhu D.S. : Composite Weather Index for Response Studies; Symposium on Effects of Weather on Agricultural Production, Calcutta, Feb. 1969.

6 Vaidyanathan, A. : Influence of Weather on Crop Yields: A Review of Agro-meteorologists' Research, IJAE, Apr.-June, 1980.

4.2 In the subsequent sections of this chapter, the All India Co-ordinated Crop-Weather Scheme (AICWS), which happens to be the data base of the empirical studies, will be discussed first, to be followed by^a critical evaluation of the studies themselves.

II

4.3 In pursuance of the recommendation of the Royal Commission on Agriculture (1928), the India Meteorological Department (IMD) commenced work on agricultural meteorology by setting up a new and separate division of 'Agrimet' in 1932. The objective was to encourage proper scientific study of the relation between weather and plants through (i) macroanalysis of distribution and variability of rainfall, and estimation of evaporation and crop-weather requirements, as well as through (ii) micro-studies of climatic variables in cooperation with agricultural institutes and state agriculture departments which would provide a basis for the specification of the variables in the macro-studies.

4.4 Continuous series of district-wise estimates of (a) areas sown to different crops and (b) crop-yield per acre, were available from 'Season and Crop Reports' beforehand. The IMD, too, had been collecting systematic meteorological data on rainfall, temperature and wind, etc., at a network of weather-reporting stations alongwith a denser

network of rain gauge stations which recorded regular rainfall in all states. The Agrimet started with examining the existing time-series and commenced some preliminary correlation studies with the objective of exploring possibilities of forecasting crop-yields as functions of weather factors.

4.5 But, the available data suffered from serious drawbacks and hence, did not prove useful for such studies. The crop-yield data were not only scanty, but also were a subjective guess-work of revenue officials. Similarly, in the case of weather-data, the observing stations were usually located in easily accessible urban areas, far away from the actual field environment.⁷

4.6 The Agrimet, then, turned to the more precise data recorded at Agricultural Experiment stations, where although the data were scanty, yet an analysis of variance always brought out the very important fact that the yield-variability from year to year (i.e., due to weather) was practically as high as that attributable to all the factors combined, such as variety, treatment, manure, etc..⁸ But the insufficiency of data led to the setting up of the Central Agrimet Observatory

7 It ought to be borne in mind that the purposes behind the collection of the two different sets of data were different - one, collection of revenue; and the other, to predict weather.

8 Sreenivasan, P.S. P Studies in Agricultural Meteorology of Some Field Crops; Unpublished Ph.D. thesis at Mahatma Phule Krishi Vidyapeeth, Rahuri (1970).

in the Agricultural College Farm at Poona in 1933, to initiate necessary investigations of the micro-climates of the typical crops and to evolve techniques for securing accurate estimates of the periodical development or growth observations of selected crops during their life-time. This provided the basis for launching, in 1945, the All India Co-ordinated Crop-Weather Scheme (AICWS) by the Indian Council of Agricultural Research (also co-sponsored by ICSC and ICCR) for periodical observations on the growth and development of crops in selected fields at a network of Crop-Weather Observatories situated at important experimental farms in different states in India.⁹ The objective of the Scheme was "the collection of basic meteorological and crop data in a farm environment with a view to studying inter-relationships, with an attempt to study the effect of individual climatic elements like temperature and rainfall on crop-yield"¹⁰ The crops^s chosen for the study on all-India basis were paddy, wheat and jowar, to which were added cotton and sugarcane in 1946 and 1947 respectively.¹¹

9 Ramdas, L.A. : Crops and Weather in India, ICAR monograph, New Delhi, 1960.

10 Report of the National Commission on Agriculture, Part IV, pp. 2.

11 Mallik, A.K. P Effects of Weather on Crop Growth and Yield at Government Experimental Farm at Dharwar; Journal of Biological Sciences, June 1958.

4.7 Under the AICWS, there were 125 observatories of which 50 recorded detailed and systematic observations, on a uniform basis, regarding the growth and yield of the selected crops as well as the meteorological factors experienced by the crop during its life cycle. The scope and design behind this endeavour was as follows: "At each station, two varieties of the crop under observation are grown according to the following lay-out plan, with six plots under each variety.

V_1	V_2	V_2	V_1	V_1	V_2
V_1	V_2	V_2	V_1	V_1	V_2

V_1 = I variety

V_2 = II variety.

The size of the plot is $\frac{1}{40}$ acre. The sampling unit is 8 ft. length made up of two parallel 4 ft. length (ultimate units), in adjacent rows. Three such samples are selected by randomisation from each half of the plot, giving 36 samples or 72 ultimate units, for each variety. The two end plants of each ultimate unit come under measurement.

4.8 "The height measurements are thus made on 144 plants in all, for each variety, selected by randomisation. The height is measured from the ground upto the base (junctura) of the topmost fully opened leaf. The height values represent the average of the heights, from the ground to the junctura of the topmost fully opened leaf, based on the

measurements made on 144 plants of each variety selected by randomisation, at a time when the height of the crop has reached the maximum. The yield values, however, are based on the yield of all the six plots of each variety, pooled together."¹²

4.9 "The data are tabulated on standard printed forms, according to standard weeks and periods of the 'Gowers Year'. The advantage of using 'Gowers Year' is that each standard week of the year ~~is~~ covers the same calendar dates every year and it is, therefore, convenient to obtain normals for each standard week, when data for a sufficiently large number of years are accumulated. The tabulated data are promptly scrutinized at the office of the Director of Agricultural Meteorology and care is taken to ensure that the accumulating data remain free of any serious shortcomings.

4.10 "After scrutiny, both the meteorological and the crop data for each crop, for each year are represented pictorially in crop-weather diagrams Such diagrams summarise a wealth of data depicted the life history of the crop from sowing to harvest, indicating the dates of commencement and completion of various growth phases such as germination, tillering, or branching, elongation, flowering and yield."¹³

12 Mallik, A.K. : Height and Yield of Kharif Jowar in Relation to Rainfall during Vegetative Growth; IJMG, Vol.9, No. 4, 1958, pp. 377.

13 Mallik, A.K. : Op.cit., JBS, 1958.

4.11 Under the Scheme, in the above-mentioned design, a huge mass of information was collected, though the collection and publication of the data were rather fitful and incomplete. The Scheme in its original form was discontinued from the late sixties. The present position is explained thus : "In the last two decades, large changes have taken place in the country in Agricultural Production Technology. Old crop varieties and the agricultural operations have also undergone substantial changes. To be in tune with and to cater to the need of these new developments, the precision crop-observations are being replaced by those requiring the recording of simple observations on the growth, development and yield of important crop varieties from all agrometeorological stations, - such that enough data becomes available for analysis in a short period of time The information collected from the network of observations is also being mapped for issue as an Agro-climatic atlas of India. The crop and meteorological data under the crop-weather scheme are being published in the form of crop-weather diagrams, which are a factual summary of the week by week progress of the crop growth and the weather conditions experienced by it."¹⁴

4.12 The major advantage that has decidedly accrued from the scheme is that a network of more than hundred well-equipped agrometeorological observatories all over the country have

¹⁴ Sarker, R.P. : Meteorology at the Service of Agriculture; Mimeo. (1977), p. 2 (Quoted by Vaidyanathan, op.cit., p. 129).

been recording data on sunshine, air temperature, (maximum, minimum, dry, wet and terrestrial minimum thermometers), soil temperature, wind, rainfall, evaporation from water surface and evaporation from soil surface.¹⁵

4.13 Precipitation happens to be the principal climatological factor affecting Indian agriculture, because, although geographically India falls within latitudes which encompasses all the deserts in the northern hemisphere; it is the strategic location of hills and mountains that has saved her from aridity.¹⁶ Nature has been bountiful in bestowing the countryside with all factors conducive to rich agricultural economy except one : the crucial water supply which depends mostly upon the whims of the rain-god.¹⁷ The origin of natural water-supply in India is primarily from four monsoon currents -

- (i) South-West monsoon from June to September
- (ii) Post-Monsoon from October to December
- (iii) Winter monsoon in January and February
- (iv) Summer monsoon from March to May.

15 Report of the National Commission on Agriculture; Part IV, p. 24.

16 Sen, S.R. : Droughts in India : Certain Dimensional Considerations; Symposium of Planning for Drought Areas, New Delhi, Mar. 1969.

17 Ray, S.K. : Weather and Reserve Stocks for Foodgrains; EPW, Sept., 1971.

Of these, the South-West monsoon accounts for two-thirds of the annual precipitation for most areas and influences directly more than 60 per cent of India's total foodgrain production.¹⁸ The uneven distribution of rainfall over India is due to wind currents as well as due to the elevation and topography of the land; and the pattern of rainfall distribution is primarily responsible for differences in land-use, cropping-pattern, settlement and density of population in different parts of the country. This does not, however, mean that efforts have been or should be slackened to collect data with regard to other agrometeorological factors. The empirical works on weather-crop relations, to be discussed in the next section, show the attempts in the direction of bringing out the effect of other meteorological parameters like temperature, sunshine and humidity on crop-response as well.

III

4.14 Studies in the field of weather-crop analysis in India commenced as early as in 1910. However, there is no evidence of any research in the direction of establishing relationship between different facts and stages of weather and its impact on the different stages of crop-growth, as it has been done in other countries where serious agronomic

18 Ray, S.K. : Op.cit.

research is conducted.¹⁹ Research on crop-weather relation in India has been essentially of a statistical nature where, lately, the objective has been to investigate on drought climatology and to develop techniques for issue of crop-yield forecasts using meteorological parameters.²⁰

4.15 As pointed out in the last section, although other meteorological factors are recognised and taken into account in such studies, precipitation or rainfall happens to be the principal weather factor of concern for the Indian researchers. Weather can be treated either as a single aggregate measure of weather factor or factors during the entire production period, or at different periods of plant-growth. In the following review of the studies, it will be seen that in a few early ones, the attempt has been to correlate weather factors, mainly rainfall and its distribution, with the areas sown as well as the crop-yield. The notion of an upper and a lower limit to 'useful' rainfall, beyond which the plant-growth is adversely affected, has resulted in a few studies where the limits have been sought to be established statistically by fitting a quadratic function with total rainfall (or other meteorological factor) as an independent

19 Detailed in Chapter Three. In the studies abroad, there have been attempts to evaluate the coefficients relating crop-responses to climatological or derived agrometeorological data, e.g., the Baier's model, the FYNM model.

20 This was mainly due to the recommendation of the Planning Commission in the latter half of 1967. (Report of the National Commission on Agriculture, Part IV)

variable. In another study, on the basis of general agronomic knowledge, the relevant levels of rainfall, the number of rainy days, etc., a single measure of 'maximum effective rainfall' is calculated to be fitted into the analysis. But mostly there have been studies where regression techniques have been employed to analyse the crop weather relationships using weather factors alone as the independent variables, as well as some, where the weather factors along with certain agronomic results are taken as the explanatory variables so as to arrive at a forecasting formula.

4.16 In the very first study of its kind in India, S.M. Jacob²¹ tried to correlate the area under matured crop with rainfall, and also, specifically dealt with the effect of varying distributions of rainfall on the important crops, considered separately, in the Jullundur tehsil of Jullundur District in the Dhoaba between Beas and Sutlej, taking into account data from 1886 to 1915. He correlated the areas sown (to all crops) to rainfalls in August, September and October separately, too. The nett or partial coefficients of correlation of area sown with wheat in the well-irrigated area with rainfalls during August, September and October were -0.79, -0.86 and -0.74 respectively; and that in the unirrigated area were + 0.57,

21 Jacob, S.M. : 'On the Correlation of Areas of Matured Crops and the Rainfall and Certain Allied Problems in Agriculture and Methodology'; Memoirs of the Asiatic Society of Bengal, 1910; and 'Correlation of Rainfall and the Succeeding Crop with special reference to Punjab'; Memoirs of IMD, 1916.

+0.72 and +0.59 respectively. The equation expressing area of wheat sown in the well-irrigated zone in terms of rainfall departures from the mean rainfall of each month was arrived at :

$$S = 18,390 - 570 R_8 - 750 R_9 - 4,300 R_{10}$$

where $R_n \Rightarrow$ the rainfall departure from the mean in the n^{th} month. To bring in the relative effects of August, September and October rainfall (computed to be in the ratio of 2:3:1), the regression coefficients are multiplied with their respective standard deviations and appropriate correction for the number of wells is also introduced. Finally, Jacob arrives at a multiple coefficient of correlation equal to 0.89 between the sown area of wheat and the weighted rainfall in the well-irrigated region, and that of 0.77 in the unirrigated region.

4.17 The underlying assumptions in this analysis are that rainfalls in the months considered are not correlated to each other; and that all departures of rain above the mean are beneficial and vice versa. The logic behind the weighting device employed herein, as well as the presumption of linear relation throughout is not comprehensible. Besides, obviously acreage or areas sown depends not only upon the rainfall, but also on other important factors, such as the crop-prices, the prevalent culture and above all the trend, which, for the period considered in the study, was rising.

4.18 At the beginning of the AICWS, Mallik et al²² carried

22 Mallik, A.K. : 'Effects of Weather on Crop Growth and
(contd...)

out some correlation studies to establish separate or independent statistical relationship between the yield rate of a particular crop and certain number of weather and agronomic variables relating to the crop. The curiosity was to see if short series, of say 10 years, may be utilized to make some preliminary examinations and indicate conclusions. The weather variables are rainfall or precipitation, number of hours of bright sunshine and the number of cloudy days computed from the number of hours of bright sunshine received. For this purpose Mallik defines a standard or normal "Grower's Year" for a crop where the period of plant growth is fixed in calendar terms. He thereby ignores the variation, if any, in the growth period for a crop from year to year arising out of the changes in the date of sowing of the crop. Given the Grower's Year, he divides this into weeks, and observations of the weather variables separately for everyone of these weeks are regressed against the yield rate. Similarly, he takes some agronomic features like the number of plants, number of tillers, height of the plant and the number of earheads or flowers, and regresses each of these separately with the yield

22 (contd.)

Yield at Experimental Farm at Dharwar'; Journal of Biological Sciences, Vol. 1/1, June 1958; 'Height and Yield of Kharif Jowar in Relation to Rainfall during Vegetative Growth', IJMG, Vol. 9/4, 1958; and Mallik, A.K., et al : 'Preliminary Studies in Crop-Weather Relationships'; IJMG, Vol. 11/4, 1960.

rate of the crop. This sort of analysis is carried out for wheat, jowar, cotton crops at Dharwar, where the number of annual observations in each case was 9 (from 1946-47 to 1954-55); and kharif jowar at Dharwar, Parbhani, Jalgaon, Akola and Nagpur where the procedure of substituting replication in space for replication in time is adopted. The number of station-years in the latter case was 48.

4.19 From this type of simple correlation analysis, Mallik draws the following types of conclusions : that 'unseasonal rain and cloudy weather create conditions favourable for severe attack of rust in the case of wheat'; 'jowar crop at Dharwar is rather susceptible to excessive rain during the growing period'; 'spell of cloudy and rainy weather extending over 3 consecutive weeks during the growing season of cotton appears to create conditions favourable for pests like shoot borer and red-cotton bugs'; 'greater rainfall during the four weeks preceding the branching period, as well as during the period, and more rainy days during branching increased the number of branches', etc..²³

4.20 It is difficult to see how Mallik can draw from these sets of simple correlations such conclusions. In the first place, no great significance can be attached to the correlation between the rainfall in a particular week in the crop season and the yield rate of crop; the yield would depend upon the pattern of rainfall that precedes and succeeds that week's.

23 Ibid.

Even if in some sense rainfall in a particular week is crucial, the magnitude of its impact on the yield cannot be judged from such simple correlation exercises. Secondly, the particular agronomic characteristics of the plant growth will be mostly dependent upon variations in the climatic factor from year to year, given, of course, the soil, the variety of the crop and other inputs. To take any of these agronomic characteristics as independent variable does not help establish any relationship between yield rate and weather. Nor does it by itself say anything about how rainfall may be affecting a particular growth feature of the plant. Consequently, one is at best left with indications of a few possible relevant factors (including rainfall in some weeks) for further careful investigations. It has at the same time to be recognised that the variables that show statistically insignificant simple correlation may not all be unimportant.

4.21 In another study by Cummings and Roy,²⁴ where the influence of rainfall on foodgrain production is analysed so as to separate out the impact of the new agricultural strategy on the agricultural production, rainfall indices have been constructed; and assuming a relatively constant technology,

²⁴ Cummings, Ralph W. Jr. & S.K. Ray : '1968-69 Foodgrain Production : Relative Contribution of Weather and New Technology'; EPW, Sept. 27, 1969; and 'The New Agricultural Strategy: Its Contribution to 1967-68 Production; EPW, Mar. 29, 1969.

the yield is hypothesized to be a function of rainfall and time, which serves as a proxy for imports. The methodology of constructing the rainfall indices for different crops includes the following steps:

- (a) rainfall data, reported for 31 major zones, are combined into state averages by weighting each zone by its cultivated area;
- (b) the total quantity of rainfall affecting the crop production (e.g. June-February, in case of wheat) is calculated for each major crop-growing state; the rainfall data being available for only particular groups of months, the periodic specification for rainfall is constrained by this.
- (c) state rainfall figures are combined into all-India averages by weighting each year's rainfall in the crop-growing states by this crop-production in that year;
- (d) the all-India averages are converted into percentages of the normal (=100), based on the average of crop-production during 1959-62.

The linear regression fitted to the 1951-52 through 1966-67 data shows that a one unit change in the index of rainfall, holding time as constant, can be expected to increase the cereal yield by almost 2.5 pounds per acre (a total of 2,69,000 tonnes, when multiplied by the approximate area sown).

4.22 Recognising that both too much as well as too little rainfall can be detrimental to crop-yield, a quadratic function has also been fitted, which gives an 'optimal' production rainfall index at 105.8; and the R^2 obtained equals 0.907.

4.23 In yet another study,²⁵ S.K. Ray has tried to analyse the influence of rainfall (u) on area (A), production (Y) and yield (y) for cereals as a whole and for rice separately, where three relationships have been considered :

$$A_t \text{ or } Y_t \text{ or } y_t = a_0 + a_1 t + a_2 u_t \quad \dots \quad (1)$$

$$A_t \text{ or } Y_t \text{ or } y_t = a_0 + a_1 t + a_2 u + a_3 u_t^2 \quad \dots \quad (2)$$

$$\text{Log } A_t \text{ or } \text{log } Y_t \text{ or } \text{log } y_t = a_0 + a_1 t + a_2 \text{log } u_t \quad \dots \quad (3)$$

where 't' is a linear integral-valued time variable with values 1, 2, 3 ... and 'u' is the rainfall index.

4.24 Equation (1) is linear in time and rainfall. The quadratic term u_t^2 in eqn. (2) includes the adverse effect of rainfall (too much or too little) and introduces a single curvature in the regression-surface. Consistent results would require $a_2 > 0$ and $a_3 < 0$. Eqn. (3) is the Cobb-Douglas type where variations due to rainfall is superposed over an exponential growth-curve. Since marginal increase in production is likely to decrease with increase in u , one should expect a_2 to lie between 0 and 1.

25 Ray, S.K. : 'Weather and Reserve Stocks for Foodgrains'; EPW, Sept. 1971.

4.25 The analysis shows that either of the two equations, (1) or (3), can explain more than 90 per cent of the variations in cereals area, production and yield, thereby indicating a strong positive effect of rainfall. Similar results were also obtained for rice. Eqn. (2) hardly improves the value of R^2 obtained otherwise; however, in all cases it provides u and u^2 coefficients with consistent signs.

4.26 The same method has been adopted by Sanderson and Roy,²⁶ where they have constructed rainfall indices for wheat, rice and cereals separately taking the average of twenty years (1957-58 to 1976-77) as base and have tried to project the production into future. In the multiple linear regression carried out, a single factor, fertilizer, is used to serve as a proxy for the package of modern inputs because a high degree of inter-correlation between fertilizer, the High Yielding Varieties and irrigation was noticed. The results for cereal, wheat and rice, respectively were -

$$Y = 211.78 + 5.00 x_1 + 12.27 x_2 \quad \text{with } R^2 = 0.94$$

(6.59) (13.54)

$$Y = 476.13 + 2.49 x_1 + 20.49 x_2 \quad \text{with } R^2 = 0.93$$

(2.58) (16.16)

$$Y = 277.80 + 6.67 x_1 + 7.31 x_2 \quad \text{with } R^2 = 0.87.$$

(6.23) (6.15)

where $Y \Rightarrow$ yield of the crop; $x_1 \Rightarrow$ rainfall index for the crop and $x_2 \Rightarrow$ fertilizer use (kg/hectare); and the values in parantheses stand for the t - values. With the equations,

²⁶ Sanderson, Fred H. & Shyamal Roy : Food Trends and Prospects in India; Allied Publishers Pvt.Ltd., 1980.

the observed yields have been corrected for the effects of weather; and the effect of technology in accelerating the rate of increase in yields evaluated. ¶ In case of rice, the weather-adjusted yields increase at a steady rate of @ 1.3%.

4.27 In evaluating Ray's rainfall indices, it can be pointed out that the significant coefficients and the high values of R^2 obtained are not sufficient to attach confidence on the impressive results, because the highly significant trend-variable may practically explain most of the variations. Further, it is not clear why production figures used as weights while computing the all-India average when area-weights are used in getting the state averages from zonal rainfall data.

4.28 Harold Mann,²⁷ the celebrated pioneer of village surveys in India, was deeply concerned with the frequency of droughts and famines in the Deccan where he worked as Director of Agriculture over a long period. He tried to examine rainfall data in order to see if he could find out some regularity in its changes over long years so that one could with some confidence anticipate or predict droughts. For this purpose Mann calculated what he calls 'the maximum effective rainfall' during a season or year, for a long period of years from 1865 to 1938. The method of calculating 'maximum effective rainfall' precludes isolated rainfall less than 0.1", but counts it

²⁷ Mann, Harold H. : A Study of Rainfall in the Bombay Deccan, 1865-1938; ISAE, 1955.

in a rainy season if it is continuous. Rainfall under 0.2" is not counted in December and January and no fall at all is counted in February, March and April. Also, in the first half of May, no fall is counted unless followed by a rainfall substantial enough for sowing within 10 days. At the commencement of rainy season nothing is counted until there is a practically continuous fall of over 1". During the growing season, no rainfall below 0.1" is counted unless in immediate continuation of other rain falls. If more than 2" of rain falls in one day, all rain above that amount is excluded.

4.29 Plotting this on a timescale, Mann found fluctuation, which however were so irregular that no basis for prediction could be obtained.

4.30 The concept of 'effective rainfall' by its very nature implies the rainfall affecting crop yield. As seen above, Mann used different elements in the rainfall pattern on the basis of his knowledge about what may be effective for crop growth. But ultimately this expected ~~xxx~~ measure has to be tested against actual yield performance in order to see if the rainfall measure is devised was really 'effective'. Mann set out to do this through a detailed statistical analysis of the components of the effective rainfall and the agricultural production. The factors so taken into account were the changes in the dates of commencement and cessation of the rains, changes in the distribution of the 'effective rainfall', relationship between the effective rainfall and the agricultural

production and the extent of correlation between the wetness of soil, as determined by the amount and distribution of rainfall, and the agricultural productivity. The technique employed was that of simple correlation analysis.

4.31 Unfortunately, all these simple regressions had very poor correlations with the agricultural productivity, thus telling upon the effectiveness of the whole concept of 'maximum effective rainfall' and thence, the whole of his analysis. His location of faint cyclic phenomenon in the quantum of 'effective rainfall', too, seems to be of no particular significance because, apparently the 'effective rainfall' was not really effective after all, as his results would show. Neither do his conclusions preclude the possibility of locating such cycles with a better index of effective rainfall devised possibly in another way.

4.32 As indicated earlier, some regression studies also involve measurement of weather factors and their impacts at different stages of plant growth. Multiple linear as well as curvilinear regression techniques have been employed in such cases to estimate the relationship between meteorological factors and the crop-outcomes. In one such study, Sreenivasan and Banerjee²⁸ present the results of a linear multiple regression of the yield of rabi jowar in Raichur on mean maximum temperature, mean minimum temperature, total rainfall

²⁸ Sreenivasan P.S. and J.R. Banerjee : 'Studies in the Forecasting of Yield by Curvilinear Technique'; IJMG, Vol.24/1, 1973.

and the number of rainy days, where the obtained multiple coefficient of correlation was 0.54. In the same study, the same body of observations is made subject to multiple curvilinear regression²⁹ which explains a much higher proportion of the variations in the yield. The IMD unit set up at the insistence of the recommendation of the Planning Commission to 'develop techniques for issue of crop-yield forecasts' came up with forecasting formulae for the yields of Kharif rice in 22 meteorological subdivisions and wheat in 9 subdivisions³⁰ using the same technique. Two such studies³¹ are reviewing in the following paragraphs to illustrate the methodology. The first paper, by Das and Vidhate, relates to wheat in Uttar Pradesh taken as a whole and uses data relating to average yield per acre and average rainfall,

29 Ezekiel, M. & K.A. Fox : Methods of Correlation and Regression Analysis; John Wiley & Sons Inc., 1959.

The starting point is the linear multiple regression of standard type:

$$Y = a_0 + a_1X_1 + a_2X_2 + \dots + a_nX_n$$

The postulation is that the relation between Y and each of the independent variables may have different, and not necessarily linear, forms. The true relationship would be -

$$Y = a'_0 + a'_1 f_1(X_1) + a'_2 f_2(X_2) + \dots + a'_n f_n(X_n)$$

The nature and shape of $f_1(X_1)$ are obtained by a process of successive approximation using free-hand curves. The multiple and partial correlation coefficients are then estimated by feeding a free hand approximation of the curvilinear functions into the second equation.

30 Sarker, R.P. : Meteorology at the Service of Agriculture, IMD Monograph, 1977, pp. 7.

31 Das, J.C. & S.G. Vidhate : 'Forecasting Wheat Yield with the Help of Weather Parameters - Part II, Uttar Pradesh'; IMD PPSR No.160, 1971; AND

Morey, P.E. & Madnani, M.L. : 'Regression Equation for

(contd...)

temperature (maximum, minimum and mean) and humidity during the growing season from 1921 to 1966. The procedure of selecting the significant meteorological factors is described thus :

"To get the periods in which meteorological factors have a significant effect on yield, the linear correlation between yield and rainfall, temperature and humidity have been worked out for overlapping periods of seven days to ninety days of the crop growing season All the correlations have been examined and from them the periods in which a particular weather element is significantly correlated with yield are marked out. By using these factors, the multiple correlation with yield has been calculated. Some of the factors used are not significant at 5% level. In order to find out the combination in which the parameters used are all significant at at least 5% level multiple correlation coefficients of all combinations (are calculated) dropping gradually one or more variables till a combination is found out where all parameters used are significant."³²

4.33 All values are averaged for the whole state. The increasing trend in yield observed since 1951, being assumed to be due to various development programmes, are sought to be taken into account by introducing 'a suitable time scale linear variable in the regression analysis'. The final

31 (contd)

Forecasting Yield of Paddy/Rice on the basis of Weather Parameters and Chemical & Fertilizer - Tamilnadu'; Met. Monograph, IMD, 1973 (Mimeo.)

32 Das, J.C. & Vidhate, S.G. P Op.cit., pp. 3

regression includes seven variables which together explain 73 per cent of the observed variance in yield in 1921-65 and 70 per cent in 1951-65. The extrapolation shows that predicted yields in 1966-70 are closer to the observed values when computed from the regression for the longer time series (the difference being within 4 per cent) than from the regression for 1950-65 (where the difference is around 10 per cent).

4.34 The other paper by Morey and Madnani attempts a similar exercise for kharif paddy in Tamilnadu taking into account data from 1947 to 1970. Prompted by the large departures in the estimated yield on the basis of technique developed in 1970 from the reported yield, it is hypothesized that this was due to increased use of fertilizer and the high yielding varieties. Hence data relating to fertilizer use is used as another parameter alongwith an independent technological trend variable. The explanatory variables finally selected for the regression are—the rainfall from 4th to 10th April; range of temperature from 12th to 21st June; average cloud amount from 3rd to 9th July; average cloud amount from 12th August to 22nd August; fertilizer consumption and the technological trend. The variables together explain ~~92~~ 96.3 per cent of the variations. Extrapolations for two succeeding seasons show a difference between the reported and the estimated yield to the extent of 6 per cent in the first year and 1 per cent in the second.

4.35 Similar exercises have been attempted for other regions and other crops, the details of which are tabulated at the end of this chapter. The regression equations are found to explain the variations in the crop-yield to varying extents, ranging from 68% to 97%. Extrapolations show that a few of them did well in forecasting yields for at least a four-year period beyond the time span of the series; but, this can be so only in some years, in others it can be much wider. This is because, in spite of a very high value of R^2 , the predictive power of the regression is uncertain, and fundamentally dependant upon the exact specification of the functional form which may change over time when constructed in a trial and error method without any scientific logic at the base. Therefore, this type of approach leaves one rather uneasy from a methodological viewpoint especially when trying to understand the nature of crop-weather relations. It does not distinguish between irrigated and non-irrigated areas while aggregating for a region or a state, whereas the impact of a weather element, e.g., rainfall, is apt to be different in the two cases. Similarly, averaging the values of meteorological parameters over a region or a state as large and as varied in climatic conditions as Uttar Pradesh is questionable too. Besides, the approach to screening the explanatory variables using R^2 and tests of significance of the coefficients as the basis, is highly empirical and lacks any underlying theory or a consistent hypothesis.

4.36 A few attempts have also been made using the 'regression integral' technique of Fisher where the primary assumption is that the effect of any weather factor on a crop changes gradually and continuously during the year; and therefore, the weather factor is aggregated during shorter periods into which the year is subdivided. Nair and Bose³³ have tried to relate the yield of cotton at Sarkhand (Sind) for the period 1931 to 1941 (1937 omitted) to humidity and maximum temperature for 4 months in a year, i.e., from August to November, without any significant conclusions. Kalamkar and Satakopan³⁴ measure the influence of the rainfall distribution on the cotton yields at experimental farms at Akola and Jalgaon taking 28 and 33 year's data respectively. They observe from the regression coefficients that there is a general similarity in the response for both the stations except towards the end of the season. Their conclusion was that an additional inch of rain in the 4th week of May has adverse effect as well as heavy and continuous rainfall in the latter half of July and the first half of August on the yield. Shaha and

33 Nair, K.R. and P. Bose : 'Influence of Humidity and Temperature on the Yield of Cotton'; Sankhya, Vol. 7, Part 2, 1945.

They conclude, "On available evidence there is no significant influence of temperature and humidity on the yields of cotton. It must, however, be remembered that owing to scantiness of material analysed here, any but large influence might well remain undetected."

34 Kalamkar, R.J. and Satakopan, V. : 'The Influence of the Rainfall Distribution on the Cotton Yields at the Government Experimental Farms at Akola and Jalgaon'; IJAS, Vol.10, 1940.

Banerjee³⁵ examine the influence of rainfall, humidity, sunshine, maximum and minimum temperatures on the yield of cotton at Coimbatore, employing the same technique. Again, like Kalamkar and Satakopan, they admit that the significance of the meteorological factors could not be ascertained clearly, except the stray conclusions that more sunshine during the crop period and more rainfall upto the middle of January were beneficial to the cotton crop, and that minimum temperature plays the most important role in explaining about 72 per cent of the total variation in its yield. P.S. Sreenivasan,³⁶ in analysing the effects of the distribution of rainfall on cotton yield in Madhya Pradesh, as well as on wheat yield at Jalgaon and Niphad stations, adopts this technique along with other techniques of simple regression taking only crop features/only meteorological factors/ selected weather as well as crop features, as the independent variables; and attempts a comparison of the different methods. Although he finds a good agreement between the actual and the estimated yield in all the methods, he concludes, that estimation of yield from rainfall in selected periods is more reliable than in the Fisherian method.

35 Shaha, S.K. & Banerjee, J.R. : 'Influence of Rainfall, Humidity, Sunshine, Maximum and Minimum Temperature on the Yield of Cotton at Coimbatore'; IJMHG, Vol. 26/4, 1975.

36 Sreenivasan, P.S. : 'Influence of Rainfall in the Yield of Cotton in Madhya Pradesh', IJAS, Vol. 43/9, 1973; and Studies in Agricultural Meteorology of Some Field Crops; Unpublished Ph.D. thesis at Mahatma Phule Krishi Vidyapeeth, Rahuri, 1970.

4.37 In the more recent efforts of quantitative crop-weather studies, however, crop-characters along with the meteorological variables and the final yield are regressed. The amount of variability in crop-characters, and the simple as well as multiple coefficients of correlation and regression between the various character and the final yield are calculated. In one such study,³⁷ Sreenivasan finds that the number of ear-heads has the highest positive correlation with the yield of wheat (0.7971), which alongwith other characters such as the germination per centage, maximum number of shoots per sample, maximum height, etc., gives a multiple coefficient of correlation equal to 0.8567. In the same study, the linear correlation between the estimated and the actual yield was found to be as high as 0.9602.

4.38 In this line, Sreenivasan³⁸ develops a technique of his own for the selection of meteorological variables to be included in the regression analysis - "Different weather factors often play the dominant role during the different phytophases of the crop. Thus, during the germination phase of wheat, which is normally sown under optimum soil moisture conditions, the warmth in the soil may be the deciding factor for this phenomenon. Similarly, during the next phase of crown-root initiation, the rainfall may be the deciding factor.

37 Sreenivasan, P.S. : 'Crop Growth as an Indicator of the Final Yields - Wheat Crop'; IJMG, Vol. 9/2, 1958.

38 Sreenivasan, P.S. : Unpublished Ph.D. thesis, Op.cit.

Therefore, the trend in the linear correlation of the weather factor series are worked out in the first instance. These linear correlations are then evaluated for larger over-lapping periods of two-weeks, three weeks, etc., and the optimum lengths of the significant periods are determined. Thus, for wheat in Madhya Pradesh, the significant meteorological factors influencing the yield favourably may be (i) three weeks' pre-sowing rainfall; (ii) 3 weeks' rainfall at the time of crown-root formation; (iii) temperatures at the critical phase of establishment of the crop; and (iv) any rain during grain formation. In addition to these factors, the density of plant population may influence the yield independently. Therefore, these five factors may be used as independent variables to determine the yield by multiple regression technique."³⁹

In his analysis of data over 22 years (1947-'69) at Jalgaon and Niphad stations, Sreenivasan selects the weather variables to be - rainfall during standard week 17 to 23 (R_1), week 26 to 28 (R_2), week 38 to 41 (R_3) and week 44 to 47 (R_4) as well as the maximum temperature in the 46th week (X_5). Evaluating the contribution in the total variation in the yield, he concludes that R_1 , R_2 and R_3 alone account for two-third of the variation at Jalgaon. The inclusion of rainfall during the crown-root initiation period raises the multiple coefficient of correlation to 0.909 in Jalgaon and

39 Ibid, pp. 152-153.

to 0.837 in Niphad. In the case of the latter, it still increases if the temperature in the 47th week is included, to 0.900.

4.39 Sreenivasan, on the basis of the coefficients of determination, concludes that his method, where he makes use of selected weather elements along with crop-attributes, was the most efficient not only because it explains more percentage of the variation in the yield, but also because it can give forecasts much early on the basis of weather factors and crop characteristics included in the model which can be continuously improved with the march of the growing season by taking into account the remaining factors. However, in comparing and selecting one technique over another, it must be remembered that a high R^2 is not a sufficient basis. Unless the underlying model is firmly grounded on a theoretically sound and consistent hypothesis derived from the relative disciplines, its utility for understanding crop-weather relation remains doubtful, no matter how high the R^2 .⁴⁰ Further, taking the crop characters to be influencing the yield independently is highly questionable, because the crop characters are themselves very highly influenced by the weather factors. Thus, the multi-collinearity arising thereof may not hinder the predictive nature of the model, but sheds little light in understanding the crop-weather relationship.

⁴⁰ Ezekiel, M. & K.A. Fox : Op. cit., pp. 240-241.

4.40 To sum up, crop-weather studies in India have been decidedly statistical in nature. There seems to have been no elaborate use of the precious AICWS data except in some correlation studies to assess the strength of relationship between some weather elements and certain crop features. The forecasting models based on macro data, being highly empirical in their approach, despite seeming to be quite good for statistical predictions of yield, are of doubtful value for understanding weather-crop relations. The data collected 'uniformly' from such a large network of experimental stations could very well have been utilized in the construction of weather-indices as suggested by Shaw and Stallings to bring out the net impact of weather in the variations of crop-yield, but surprisingly it has not been done.

Table I
Forecasting Formulae for the Yield of Paddy/Rice and Wheat

Sl.No. of Equation (1)	Crop (2)	Area/Region (3)	Author/s (4)	Period of study (No. of Years) (5)	Mean Yield (lb/acre) (6)	Standard Deviation (7)	Coefficient of Variation (8)	Regression Equation (t-values in parentheses) (9)	MCC (10)	R ² (11)	Remarks (12)
1.	Paddy/Rice	Gengetic West Bengal	J.C. Das and A.K. Mehra	1937 to 1966 (30 yrs)	922.9	141.5	15	$X_1^1 = 697.652 + 19.684X_2 - 121.638X_3 + 8.141X_4 - 78.102X_5 + 15.854X_6$ <p style="text-align: center;">(3.77) (3.85) (2.09) (2.91) (6.20)</p>	.869	.755	Satisfactory
2.	-do-	Bihar Plateau	-do-	1930 to 1965 (36 yrs)	748.5	117.4	16	$X_1^1 = 717.841 - 5.577X_2 + 19.187X_3 - 40.888X_4 + 19.812X_5 + 12.003X_6$ <p style="text-align: center;">(2.12) (2.39) (2.71) (3.37) (4.05)</p>	.841	.709	"
3.	-do-	Bihar Plains	-do-	1930 to 1965 (36 yrs)	630.2	116.2	18	$X_1^1 = 594.054 - 8.748X_2 + 12.187X_3 - 39.201X_4 + 19.240X_5 + 20.574X_6$ <p style="text-align: center;">(2.03) (2.12) (2.61) (3.29) (4.76)</p>	.839	.704	"
4.	-do-	Uttar Pradesh (East)	J.C. Das and Satish Chandra	1921 to 1965 (45 yrs)	564.3	88.9	16	$X_1^1 = 473.545 + 28.484X_2 - 1.199X_3 + 16.288X_4 - 0.197X_5 + 8.464X_6 + 12.122X_7 - 45.163X_8 + 14.123X_9 + 8.298X_{10}$ <p style="text-align: center;">(3.56) (3.38) (2.22) (2.34) (4.60) (2.02) (6.98) (2.15) (2.37)</p>	.924	.854	Extrapolation agree within 4% of actuals
5.	-do-	Uttar Pradesh (West)	-do-	-do-	624.9	106.5	17	$X_1^1 = 463.069 + 6.491X_2 + 29.052X_3 - 24.239X_4 - 6.191X_5 + 14.086X_6$ <p style="text-align: center;">(3.48) (4.06) (4.69) (2.30) (4.16)</p>	.893	.798	-do-
6.	-do-	Telangana (A.P.)	J.C. Das and P.P. Sejnani	1921 to 1947 and 1952 to 1965 (41 years)	810	141.9	18	$X_1^1 = 628.669 + 32.486X_2 - 2.161X_3 - 31.862X_4 + 18.673X_5 - 6.906X_6 + 28.201X_7 + 42.956X_8$ <p style="text-align: center;">(2.08) (2.05) (3.82) (3.02) (2.83) (3.22) (5.24)</p>	.8542	.73	Extrapolation for 3 yrs. agrees with the actuals within 7%
7.	-do-	Madhya Pradesh East	J.C. Das and M. Jayaram	1900 to 1946 (46 yrs)	612.8	116.4	19	$X_1^1 = 3193.24 + 24.04X_2 + 13.43X_3 + 23.75X_4 + 6.62X_5 - 35.26X_6 + 43.46X_7 + 6.18X_8$ <p style="text-align: center;">(4.74) (2.01) (3.20) (2.92) (5.36) (5.30) (2.10)</p>	.94	.884	-

Table I (contd.)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
8.	Paddy/ Rice	Madhya Pradesh East	J.C. Das and M. Jayaram	1951-1966 (16 years)	614.5	146.2	24	$X_1^1 = 1950.60 + 26.45X_2 + 19.57X_3 + 7.47X_4$ $+ 1.10X_5 - 23.27X_6 + 62.54X_7 + 3.91X_7$.977	.955	-
								$(2.93)^2 (1.00)^3 (1.50)^4$ $(1.24)^5 (1.32)^6 (3.94)^7 (1.83)^8$			
9.	-do-	Tamil Nadu	P.E. Moray and M.L. Mowrani	1947 to 1970 (24 yrs)	1199.7	224.7	18.73	$X_1^1 = 1149.9611 - 69.016X_2 - 40.526X_3$ $+ 45.910X_4 + 36.202X_5 + 1.419X_6$ $+ 21.157X_7$.98	.963	Extrapolations agree within 6% of the actuals
								$(1.54)^2 (3.33)^3$ $(3.72)^4 (2.58)^5 (2.90)^6$ $(4.03)^7$			
10.	-do-	Orissa	J.C. Das	1926 to 1967 (42 yrs)	633.4	123.1	19	$X_1^1 = -271.89 - 8.80X_2 + 11.02X_3 + 25.42X_4$ $+ 28.48X_5 - 50.45X_6 + 36.20X_7$.967	.936	Extrapolations agree within 7% of actuals
								$(2.42)^2 (9.81)^3 (6.92)^4$ $(5.80)^5 (7.55)^6 (11.76)^7$			
11.	-do-	Vidarbha	-do-	1921 to 1967 (47 yrs)	746.6	126.2	17	$X_1^1 = 632.24 + 19.41X_2 + 7.74X_3 + 11.65X_4$ $- 34.78X_5 + 10.34X_6 + 8.91X_7$.918	.843	-
								$(4.02)^2 (2.75)^3 (3.30)^4$ $(9.43)^5 (2.15)^6 (5.01)^7$			
12.	-do-	North Assam	P.E. Moray, G. Ramachan- dra & S.G. Vidhate	1947 to 1967 (21 yrs)	991	86.94	8.77	$X_1^1 = 1390.4048 + 20.042X_2 + 18.351X_3$ $- 16.503X_4 - 24.023X_5 - 15.660X_6$ $+ 33.930X_7$.93	.860	Extrapolation agree within 5% of actuals
								$(3.27)^2 (3.11)^3$ $(1.72)^4 (2.73)^5 (2.69)^6$ $(5.12)^7$			
13.	-do-	South Assam	-do-	1947 to 1967 (21 yrs)	993	89.60	9.01	$X_1^1 = 2501.8942 + 74.94X_2 - 12.891X_3 + 39.144X_4$ $+ 9.262X_5 + 14.060X_6 - 9.491X_7$.94	.892	Extrapolation agree within 10% of actuals
								$(2.35)^5 (1.88)^6 (3.18)^7$			
14.	-do-	Sub Himala- yan West Bengal	J.C. Das	1947-1966 (20 yrs)				$X_1^1 = 3945.33 - 148.92X_2 + 4.32X_3$ $- 11.88X_4 + 11.64X_5 - 62.33X_6 + 0.75X_7$.8267	.683	Extrapolations agrees within 5% of the actuals
								$(1.10)^2 (1.17)^3$ $(1.34)^4 (0.27)^5 (1.59)^6 (2.08)^7$			
15.	-do-	Coastal An- dhra Pradesh	-do-	1904 to 1966 (63 yrs)				$X_1^1 = 1250.85 + 6.54X_2 - 27.40X_3 + 30.07X_4$ $- 13.74X_5 - 0.81X_6 + 1.25X_7 + 1.44X_8$.9106	.830	
								$(1.15)^3 (1.75)^4 (1.53)^5$ $(1.26)^6 (1.10)^7 (8.73)^8 (6.77)^9$			
16.	-do-	Tamil Nadu	-do-	1904 to 1965 (62 yrs)				$X_1^1 = 1515.66 + 26.23X_2 + 42.66X_3 - 17.23X_4$ $- 0.37X_5 + 0.46X_6 + 1.33X_7$.8819	.778	
								$(3.33)^2 (3.65)^3 (1.03)^4$ $(1.07)^5 (5.62)^6 (5.58)^7$			
17.	-do-	Kerala	-do-	1915 to 1964 (50 yrs)				$X_1^1 = 1335.32 + 8.36X_2 - 0.18X_3 + 6.81X_4$ $- 0.20X_5 - 50.25X_6 + 1.27X_7$.9643	.930	
								$(1.28)^2 (.74)^3 (1.11)^4$ $(1.12)^5 (5.49)^6 (18.88)^7$			

Table I (contd.)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
18.	Paddy/ Rice	Coastal Mysore	J.C. Das, A.K. Mehra & M.L. Madnani	1916 to 1964 (49 yrs)				$X_1^1 = -32295.96 + 6.01X_2 - 32.69X_3$ $- 1.46X_4 + 2336.23X_5 - 41.16X_6$ $+ 0.67X_7$.8952	.801	Extrapolation agree within 2% of actuals
19.	-do-	Mysore Interior North	-do-	1906 to 1964 (53 yrs)				$X_1^1 = -69537.02 + 4704.24X_2 - 78.31X_3$ $- 64.26X_4 + 25.47X_5 - 0.40X_6 + 0.81X_7$.9241	.854	Extrapolation agree within 8% of actuals
20.	-do-	Mysore Interior South	-do-	1941 to 1964 (24 yrs)				$X_1^1 = -62153.87 + 51.49X_2 + 59.93X_3$ $- 42.89X_4 + 4599.71X_5 - 83.57X_6$ $+ 0.76X_7$.9674	.936	Extrapolation agree within 14% of actuals
21.	-do-	Konkan	J.C. Das and M.L. Madnani	1906 to 1966 (except '31, '37, '39 and '43) (57 yrs)				$X_1^1 = 101154.8 + 386.269X_2 + 7536.376X_3$ $- 140.535X_4 - 17.762X_5 + 87.894X_6$.8701	.757	In 98% of year, the diff. between esti- mated and re- ported values is less than 10% -
22.	-do-	Madhya Maharashtra	-do-	1906 to 1964 (except '31, '37 and '43) (56 yrs)				$X_1^1 = 429.539 + 33.735X_2 - 49.731X_3$ $+ 9.646X_4$.9011	.811	In 39% of years, the di- fference is less than 10%
23.	Wheat	Utter Pradesh	J.C. Das and S.G. Vidhate	1921 to 1965 (45 yrs)	715.3	79.7	11	$X_1^1 = 1278.147 + 4.390X_2 - 31.488X_3$ $+ 25.913X_4 - 21.303X_5 - 9.073X_6$ $- 6.090X_7 + 6.371X_8$.856	.734	-
24.	-do-	Punjab	J.C. Das	1918-1965 (48 yrs)	8570	131.0	15	$X_1^1 = 1083.338 + 4.330X_2 - 4.591X_3$ $- 10.872X_4 + 3.96X_5 + 6.557X_6$ $- 10.124X_7 + 11.025X_8$.9281	.862	Extrapolations agree within 5% of the actuals

Table I (contd.)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
25.	Wheat	Haryana	J.C. Das	1918-1965 (48 yrs)	812.5	176.9	22	$X_1^1 = 2638.934 - 15.457X_2 + 12.202X_3$ $- 7.268X_4 + 3.448X_5 - 11.142X_6$ $+ 21.142X_7$ (2.96) (2.00) (2.02) (1.92) (4.24) (12.90)	.9243	.854	Extrapolations agree within 8% of the actuals
26.	-do-	Gujarat	P.E. Moray, G. Ramachan- dran, S.G. Vidhate	1930 to 1968 (39 yrs)	511.4	201.4	39	$X_1^1 = -218.2223 + 6.295X_2 + 15.608X_3$ $+ 4.821X_4 + 18.841X_5 - 3.401X_6$ $+ 80.829X_7$ (3.51) (5.98) (2.33) (3.23) (3.61) (31.26)	.986	.973	Extrapolations agree within 3% of the actuals
27.	-do-	East Rajasthan	V.C. Bedekar, G. Appa Rao, G. Ramachan- dran	1952-1969 (18 yrs)	795	101.5	12.7	$X_1^1 = 1325.7 + 39.2X_2 + 4.8X_3 - 32.0X_4$ $- 39.3X_5 - 25.9X_6 + 83.0X_7$ (2.07) (3.17) (2.53) (3.49) (1.87) (2.06)	.93	.860	-
28.	-do-	Himachal Pradesh	V.C. Bedekar, G. Apparao and M.L. Medhani	1952 to 1968 (17 yrs)	601.5	131.3	21.8	$X_1^1 = 550.5 + 15.0X_2 + 41.2X_3 + 65.6X_4$ $- 23.7X_5$ (2.14) (2.30) (6.0) (5.07)	.95	.897	-

Table II

Variables used in the equations in Table I

Sl.No. of Equa- tion	Dependent Variable	Explanatory variables (Figures in paran- theses indicate p.c. of Variation accounted for by the variable)
(1)	(2)	(3)
1	X_1^1 -Yield lb/acre	X_2 - June rainfall (10.4); X_3 -Occasion of drought in July and August (25.8); X_4 -Rainy days 16/9 to 15/10 (14.2); X_5 - No.of weeks in which rainfall was either less than 25% or more than 200% of the normal during 1/10 to 28/10 (8.7); X_6 -Technological Trend Variable (16.4).
2	-do-	X_2 -Rainfall 13/6 to 23/6 (14.4); X_3 -Rainfall 5/7 to 15/7 (16.0); X_4 -Occasions of drought in July & August (12.2); X_5 -Rainy days 16/9 to 15/10 (20.0); X_6 -Techn. trend variable (8.3).
3	-do-	X_2 - Rainfall 1/6 to 21/6 (14.1); X_3 - Rainfall 7/7 to 13/7 (7.2); X_4 - Occasion of drought in July and August (16.8); X_5 - Rainy days 16/9 to 15/10 (20.9); X_6 - Tech. Trend variable (11.4).
4	-do-	X_2 - Rainfall 18/7 to 10/8; X_3 - $(X_2)^2$ (29.7); X_4 - Rainy days 2/7 to 31/8; X_5 - $(X_4)^2$ (16.4); X_6 - Rainfall 24/8 to 30/9 (16.3); X_7 - Mean cloud amount 17/7 to 28/9 (6.5); X_8 - Occasion of drought 1/8 to 15/9 (8.0); X_9 - Mean range of temp. in Sept. (4.3); X_{10} - Tech. trend variable (4.2)
5	-do-	X_2 - Rainfall 26/7 to 24/9 (44.2); X_3 - Mean cloud amount 27/7 to 1/8 (9.6); X_4 - Occasion of drought 1/8 to 15/8 (15.8); X_5 - Mean

Table II (Contd.)

(1)	(2)	(3)
		range of temp. 22/9 to 19/10 (4.3); X_6 - Tech. Trend variable (5.9)
6	X_1^1 - yield lb/acre	X_2 - Rainfall 1/7 to 21/7; X_3 - $(X_2)^2$ (11.2); X_4 - Rainfall during 30/7 to 2/8 (10.4); X_5 - Rainfall during 11/8 to 26/8 (14.0); X_6 - Rainfall 3/9 to 14/9 (7.6); X_7 - Rainfall 6/10 to 15/10 (12.8); X_8 - Tech. trend (17.0)
7 and 8	-do-	X_2 - Rainy days 24/6 to 5/7 (17.8); X_3 - Crop rainy days* 4/7 to 6/7 (11.2); X_4 - Crop rainy days 26/7 to 29/7 (8.6); X_5 - Crop rainy days 2/8 to 2/9 (18.4); X_6 - Average maximum temp. 9/8 to 12/9 (10.8); X_7 - Average cloud amount 17/9 to 10/10 (12.6); X_8 - Crop rainy days 21/9 to 30/9 (9.0)
9	-do-	X_2 - Rainfall 4/4 to 10/4 (8.4); X_3 - Range of temp. 12/6 to 21/6 (6.9); X_4 - Average cloud amount 3/7 to 9/7 (17.3); X_5 - Average cloud amount 12/8 to 22/8 (3.5); X_6 - Fertilizer data (53.4); X - Tech. trend variable (6.8).
10	-do-	X_2 - Rainy days 16/6 to 21/6 (5.2); X_3 - Rainy days 11/6 to 22/8 (28.5); X_4 - Range temp. 19/9 to 25/9 (22.4); X_5 - Rainfall 1/10 to 7/10 (12.5); X_6 - Occasions of a tropical storm affect the region during 10/10 to 18/11 (9.4); X_7 - Tech. trend (15.6).

* Crop rainy day - a day when the total precipitation is 5.0 mm or more in 24 hours and also a day when rainfall is equal to or more than 3.8 mm but less than 5.0 mm when it is separated from a preceding crop raining day by not more than 2 dry days (Das and Jayaram)

Table II (Contd.)

(1)	(2)	(3)
11	X_1^1 -yield lb/acre	X_2 - Rainfall 18/6 to 24/6 (10.5); X_3 - Rainfall 21/7 to 4/8 (15.6); X_4 - Rainfall 22/8 to 30/8 (13.3); X_5 - Occasions of drought 1/8 to 15/9 (21.3); X_6 - Rainfall 25/9 to 9/10 (14.2); X_7 - Tech. trend (9.4).
12	-do-	X_2 - Restricted rainy days 11/5 to 17/5 (22.7); X_3 - Rainfall 21/7 to 27/7 (7.4); X_4 - Rainy days days 3/8 to 9/8 (20.6); X_5 - Mean range temp. 8/9 to 23/9 (4.1); X_6 - Mean range temp. 5/10 to 11/10 (4.9); X_7 - Tech. trend ((26.3)
13	-do-	X_2 - Rainfall 1/5 to 7/5 (21.7); X_3 - Mean Max. temp. 11/7 to 31/7 (47.8); X_4 - Mean cloud amount 17/7 to 25/7 (5.0); X_5 - Rainfall 23/7 to 30/7 (5.4); X_6 - Rainy days 2/10 to 8/10 (1.6); X_7 - Mean max. temp. 6/10 to 12/10 (7.7).
14	-do-	X_2 - Restricted rainy days 16/6 to 15/7; X_3 - (X_2) ² (12.4); X_4 - Occasions during July to 15/9 when weekly rainfall total didn't exceed 44 mm (a sliding scale is used)(6.9); X_5 - Rainy days 16/9 to 15/10 (32.0); X_6 - Mean Max. temp. 16/8 to 15/9 (8.7); X_7 - Tech. trend (8.4).
15	-do-	X_2 - Rainy days in July (9.4); X_3 - Occasions in Aug. and Sept. when weekly rainfall total did not exceed 8.8 mm (sliding scale used) (13.3); X_4 - Rainy days during Oct.; X_5 - Mean temp. during Oct. (13.5); X_6 - (X_4) ² (1.1); X_7 8x8 - Tech. trend (noticed twice, 1904-'20 and 1951-66) (45.7).
16	-do-	X_2 - Rainfall 16/5 to 31/5 (35.8); X_3 - Rainfall 16/6 to 30/6 (11.2); X_4 - Mean Max. temp. during July and Aug. (2.8); X_5 - Mean min. temp. during Aug. and Sept. (7.2); X_6 and X_7 - Tech. trend variable (20.8).

Table II (Contd.)

(1)	(2)	(3)
17	X_1^1 -Yield, lb/acre	X_2 - Rainy days 16/4 to 15/5; $X_3-(X_2)^2(23.0)$; X_4 - Rainy days 16/5 to 15/6; $X_5-(X_4)^2(11.3)$; X_6 - Occasions of flood and drought 16/6 to 31/8 (27.2); X_7 - Tech. trend (31.5).
18	-do-	X_2 - Restricted rainy days 1/7 to 15/9 (36.0); X_3 - Occasions of drought and flood during Aug. & Sept. (25.2); X_4 -Rainfall in June (6.8); X_5 - Mean more temp. for July & Aug. ; $X_6-(X) (2.6)$; X_7 -Tech. trend (9.5)
19	-do-	X_2 - Mean max. temp. in July & Aug.; $X_3-(X_2)^2(9.2)$; X_4 -Occasions of drought in Aug. & Sept. (48.0); X_5 -July rainfall (5.4); X_6 - Square of June to Aug. rainfall (2.4); X_7 - Tech. trend (20.4).
20	-do-	X_2 -September rainfall (22.0); X_3 -June rainfall (20.4); X_4 -Occasions of drought in July & Aug. (11.3); X_5 -July and Aug. mean max. temp. $X_6-(X) (6.4)$; X_7 -Tech. trend (34.3).
21	-do-	X_2 -Log. of rainfall during June to Aug.; X_3 -Mean temp. July & Aug.; $X_4-(X_3)^2$; X_5 -Occasion of drought and flood during July to Sept.; X_6 -Tech. trend.
22	-do-	X_2 -Rainy days in July; X_3 -Occasion of drought in Aug.; X_4 -Rainy days 16/9 to 30/9.
23	-do-	X_2 -Rainfall 1/9 to 18/9; X_3 -Mean minimum temp. 18/11 to 28/11; X_4 -Mean max. temp. 29/11 to 10/12; X_5 -Mean max. temp. 13/12 to 27/12; X_6 -Occasions when min. temp. during Dec. & Jan. fall below 5°C; X_7 -Mean temp. 2/2 to 13/2; X_8 -Tech. trend.

Table II (Contd.)

(1)	(2)	(3)
24	X_1^1 -yield lb/acre	X_2 -Rainfall 13/9 to 16/10 (16.1); X_3 -Mean Max. temp. 22/12 to 20/1 (7.3); X_4 - Mean min. temp. 2/12 to 29/12 (14.7); X_5 -Mean min. temp. 24/1 to 3/2 (3.2); X_6 -Mean relative humidity 8/2 to 22/2 (13.1); X_7 -Occasions temp. being less than 42°F (11.7); X_8 -Tech. trend (20.1).
25	-do-	X_2 -Mean min. temp. 13/11 to 30.11(12.1); X_3 - Mean min. temp. 2/12 to 29/12 (8.4); X_4 -Mean Max. temp. 22/12 to 20/1 (9.6); X_5 -Rainfall during Nov. to Mar. (8.2); X_6 -Occasion of temp. temp. falling below 42 F (16.8); X_7 -Trend (30.3).
26	-do-	X_2 -Rainfall 3/9 to 22/9 (22.1); X_3 -Average range of temp. 29/12 to 4/1 (2.6); X_5 -Average cloud amount 4/2 to 11/2 (16.8); X_6 -Occasion of temp. falling below 45 F and rising above 95 F during Dec. to Feb. (7.5); X_7 - Trend (14.9)
27	X_1^1 -Yield, lb/acre	X_2 -Rainy days 14/8 to 20/8 (6.3); X_3 -Mean relative humidity 1/11 to 17/11 (19.4); X_4 -Rainy days 24/11 to 19/1 (22.5); X_5 -Mean Max. temp. 30/12 to 8/1 (28.8); X_6 -Crop rainy days 23/10 to 2/12 (5.5); X_7 -Tech. trend from 1967 (3.5).
28	-do-	X_2 -Rainfall 20/1 to 28/1; X_3 -Rainfall 25/10 to 2/11; X_4 -Average cloud amount 8/12 to 14/12; X_5 -Mean min. temp. during 24/2 to 1/3.

Table III

Critical Periods when Weather Elements Significantly Affect Yield of Rice

Sl. No.	Area/Region	Equation in Table I	Period	Favourable	Unfavourable	Remarks
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1.	Gangetic W.B.	1	16th Sept. to 15th Oct.	Rainy days	-	Each rainy day increases yield by 11 lbs/acre.
			July and August		Dry spell of 10 days or more	If dry spell continues for 3 weeks or more yield may reduce by 50%.
			June	Rain over Normal	-	Every additional 25 m.m. of rainfall over normal (23.6 mm) increases yield by 18 lbs/acre.
2.	Bihar	2 & 3	16th Sept. to 15th Oct.	Rainfall	Rainy days exceeding 8 to 10 days	Yield increases by 28 lbs/acre in Bihar plateau and 19 lbs/acre in Bihar Plains for each rainy day.
			June	Rainfall	Heavy rain in the first 3 weeks	-
3.	Uttar Pradesh (East)	4	1st Aug. to 15th Sept.		Absence of rain in the first 3 weeks	Yield reduces by 70% if rain is absent for 21 days or more.
			24th Aug. to 30th Sept.	Rainfall		Increases yield by 8 lbs/acre for every 25 m.m. of rain during the period.
			September	Range of temperature		Increases yield by 14 lbs/acre for each 0.6°C or 1°F increase in range of temp.
4.	Uttar Pradesh (West)	5	1st Aug. to 15th Sept.		Absence of rain for 10 days or more	Yield reduces by 35% if rain is absent for 21 days or more.
			26th July to 24th Sept.	Rainfall		Increases yield by 6 lbs/acre for every inch of rain during the period.
			27th July to 1st Aug.	Cloudiness		Each data of cloudiness increases yield by 29 lbs/acre.
5.	Telangana (AP)	6	July		Rainfall exceeding 8" in first 3 weeks	
			11th to 26th Aug. & 6th to 15th Oct.	Rainfall		Each 25 m.m. of rain during the periods increased yield by 19 lbs/acre.

Table III (contd.)

(1)	(2)	(3)	(4)	(5)	(6)	(7)
6.	Orissa	10	1st Oct. to 7th Oct.	Rainfall		Increase in yield by 24 lbs/acre for each 25 m.m. of rainfall.
			19th Sept. to 25th Sept.	Range of temperature		Increase in yield by 24 lbs/acre for each 10°F increase in range of temp.
			10th Oct. to 18th Nov.	-	Heavy rain	Decreases yield by 10 lbs/acre.
7.	Vidarbha	11	18th June to 24th June	Rainfall		Increases yield by 20 lbs/acre for each 25 m.m. of rainfall.
			22nd Aug. to 30th Aug.	Rainfall		Increases yield by 20 lbs/acre for each 25 m.m. of rainfall.
			1st July to 15th Sept.		Absence of rain for 8 days or more	If dry spell continues for 3 weeks or more, yield reduces by 40%.
8.	Sub-Himalayan W.B.	14	1st July to 15th Sept.		Dry spell for 2 weeks or more	If dry spell continues for 3 weeks or more, yield reduces by 12%.
			16th Sept. to 15th Oct.	Rainy days		Each rainy day increases yield by 11 lbs/acre.
9.	Coastal Andhra Pradesh	15	October	Rainfall		Increased yield by 20 lbs/acre for each 25 m.m. rainfall.
			Aug. to Sept.		Dry spell exceeding 3 weeks	Dry spell for more than 4 weeks reduces yield by 15 to 20%.
10.	Tamil Nadu	9 & 16	May and June	More than normal rainfall during second half of May and June in Mercara & Bhagmadala area		Rainfall exceeding normal by 20% during each period increases yield by 40 to 60 lbs/acre.
11.	Kerala	17	16th June to 1st Aug.		Dry spell of 18 days or more; 3 or more occasion of floods	Yield may decrease by about 15%.
12.	Coastal Mysore (Karnataka)	18	June		More than normal rainfall	
			August & September		Dry spell of 18 days or more	
			1st July to 15th Sept.	Restricted rainy days		
			July and August	Normal maximum temperature		

Table III (contd.)

(1)	(2)	(3)	(4)	(5)	(6)	(7)
13.	Interior Mysore (Karnataka) North	19	July	Rainfall		Increase of yield for each 25 m.m. of rain - 25 lbs/acre.
			Aug. & Sept.		18 days and more of dry spell	If dry spell continues for 28 days or more, yield can decrease 40 to 50%.
			July to Sept.	Mean maximum temp. (about 30°C)		
14.	Interior Mysore (Karnataka) (South)	20	June	Rainfall		Increase in yield for each 25 m.m. of rain - 60 lbs/acre.
			July and August		Dry spell of 18 days or more	If dry spell continues for 18 days or more, yield decreases by 15-20%.
			September	Rainfall		Yield increases by 50 lbs/acre for every 25 m.m. of rainfall.
15.	Konkan	21	1st July to 30th Sept.		Dry spell, floods on more than 30 occasions	Yield can reduce as much as 15%.
			June to Aug.	Higher rainfall		Relationship logarithmic.
			July to Sept.	Cloudiness		
			July to Aug.	Normal mean temp.		
16.	Medhya Maha- rashtra	22	July	Rainy days		Yield increases by 34 lbs/acre for each rainy day.
			August		Dry spell of 10 days or more	Dry spell of 3 weeks reduces yield by 25%.
17.	Punjab	-	1st Aug. to 15th Sept.		Absence of rain for 10 days or more	10 to 15% reduction in yield if it does not rain continuously for 21 days or more.
			25th Sept. to 9th Oct.		Rainfall	For every 25 m.m. of rain during this period, yield may reduce by 21 lbs/acre.
			4th July to 31st July	Rainfall		Increase in yield by 8 lbs/acre for every 25 m.m. of rainfall.
18.	Haryana	-	3rd Aug. to 13th Aug.	Rainy days		Increase in yield by 38 lbs/acre for each rainy day.
			19th June to 25th June	Rainfall		Increase in yield by 75 lbs/acre for each 25 m.m. of rain.

CHAPTER FIVE

CONCLUDING REMARKS

5.1 Economists' interest in the analysis of weather-crop relationships is primarily due to the economic implications of weather-variability. A precise knowledge of such relationship would help separate the impact of weather from that of other factors such as technological, economic and institutional; and thence, the formulation of suitable policies concerning not only agriculture, but also the national economy at large of which agriculture constitutes a substantial part. An agricultural supply function allowing for weather-inputs can provide insight into the economic logic governing resource-use and assessing the performance of other inputs.

5.2 In the foregoing chapters of the present study, the attempt has been to review and evaluate researches made in this direction. Specification of the true relationship of weather factors to plant characteristics and yield has been a difficult task; and most of the hypotheses in this regard have been based on trial and error without embodying well-substantiated theories of causation of yield. The empirical-statistical analysis of the weather-crop relationship, both in India and abroad, suffers from two basic handicaps: inadequacy of representative statistical data and lack of a sound theoretical a priori basis to construct the model. Therefore, trials have been made to combine all weather factors, rather

than isolating them, in the form of composite indexes especially to classify climates and draw their boundaries. The expensive and uneconomical experiments have given way to statistical methods for testing the hypotheses regarding response of plants to weather factors, where the coefficient of determination (R^2) is often computed to show the proportion of variability attributable to the weather elements. Selection of these variables is done on a trial and error basis again, looking at the R^2 . Lately, the effort has been more directed towards predicting crop-response on the basis of weather-factors adopting this technique. But, a high value of R^2 does not reflect the soundness of the underlying hypothesis, nor does it mean that the same formulation holds true for data in the preceding or the succeeding years of the time-series. Forecasts based on such statistical models might do well in cases for a few years in immediate succession; but if the variations in the observed and estimated values is 10 per cent or more, it really does not tell much since the year to year fluctuations in yield is rarely more than that. Therefore, agronomic specification of the exact nature of relationship between weather elements and the crop-response is needed to formulate a prediction-model instead of mere statistical exercises on the trial and error basis.

5.3 Another unique approach to measure the influence of weather in agricultural productivity has been through

construction of 'weather indexes' as proposed by Stallings and Shaw. The essence of this approach is that when as many variables as possible have been held constant, the remaining variation in yields (after any trends have been removed) can be considered due mainly to weather. The index is computed as the ratio of actual yields to a fitted trend. This approach not only avoids the question of exact cause-effect relationship between yield and weather, but also is devoid of the difficulties associated with the statistical attempts such as the problem of aggregation or that of defining 'time' in the context of plant phenology, etc.. Apparently it answers the economists' questions, but is limited in its explanation of only the past yields. Further, it requires sufficient number of experimental plots in different agro-climatic areas to be really useful at a national level. Surprisingly, in the Indian context there seems to have been no effort to bring out the nett effect of weather in the variations of crop-yield adopting this method, since the AICWS data apparently seems to be amenable to such an exercise. The AICWS was commendable as a well-designed enquiry and it did generate a mass of crop-weather information under controlled conditions for different parts of the country. However, the quality of this data, and its utility for analysis of weather-yield relations remain to be properly tested because, unfortunately, much of this data remains unpublished. Particularly, the forecasting

models based on them being highly empirical, need to be examined as to their explanatory and predictive power. It would be interesting to check them in more recent perspective taking into account recent data relating to yield as well as the meteorological factors. A similar interesting exercise can be done in constructing weather indexes as suggested by Shaw and Stallings.

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EPW : Economic and Political Weekly
ICAR : Indian Council of Agricultural Research
IJAE : Indian Journal of Agricultural Economics
IJAS : Indian Journal of Agricultural Sciences
IJMG : Indian Journal of Meteorology and Geophysics
IJMHG : Indian Journal of Meteorology, Hydrology and Geophysics
IMD : India Meteorology Department
ISAE : Indian Society of Agricultural Economics
JFE : Journal of Farm Economics
JISAS : Journal of the Indian Society of Agricultural Statistics
PPSR : Pre-published Scientific Report
USDA : United States Department of Agriculture
WMO : World Meteorological Organisation.

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