SYMPOSIUM ON CROP, WEATHER AND WATER RELATIONSHIP IN AGRICULTURAL PRODUCTION

A symposium on "Crop, Weather and Water Relationship in Agricultural Production" was held at the 23rd Annual Conference of the Society at Bombay on 22nd December, 1969 under the Chairmanship of Dr. V.M. Joshi, Secretary, Finance Department, Government of Maharashtra. Extended summaries of the remarks made by the persons who participated in the symposium are given in what follows :

J. S. Sharma : Crop-Weather Relationship—Areas of Study*

In India, where less than 20% of the net area sown has irrigation facilities—even this not wholly assured—weather influences crop production to a very large extent. The steep fall in foodgrains output experienced during the drought years of 1965-66 and 1966-67 from 89 million tonnes in 1964-65 to 72 and 74 million tonnes in 1965-66 and 1966-67 respectively, shows the extent to which production could go down in a bad year. Subsequently, with more or less normal weather in 1967-68 when the production recovered, a harvest of 95 million tonnes was reaped which exceeded the previous peak production of 1964-65 by 6 million tonnes. Next year, the production went down slightly to 94 million tonnes again because of unfavourable weather conditions over large parts of the country. Between 1964-65 and 1968-69 production efforts have been continuing, *e.g.* area under irrigation has been increasing, fertiliser consumption has been going up and new varieties have been sown in larger areas. The first question that arises is what is the contribution of weather to the increased production and what is the contribution of technology ? Or, in other words, in 1968-69, had the weather been normal, what would have been the level of foodgrains production or what has been the contribution of developmental efforts to the production in 1968-69. An analysis of past data on production, rainfall, inputs and other relevant information with a view to isolate the effects of technology and weather might provide an answer to this question.

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This, therefore, is the first area of study in the field of crop-weather relationships.

The next question that arises is whether on the basis of the progress of weather upto a point of time in the crop season, it is possible to forecast current year's production. At present, estimates of production become available after the crop is harvested and after the data on crop-cutting experiments conducted at harvest time are analysed. For policy purposes, however, the Government requires advance estimates of production. Can the study of weather and the past relationship between weather upto different points of time in a crop season and crop production give any clue to this question ? If necessary, other factors, such as increased use of inputs, effect of prices on acreages, etc. could also be studied. This then is the second area of study which is of interest to the Government.

It has been claimed that if weather data over long periods of time are studied, they exhibit certain symmetrical features and sometimes cyclical fluctuations could be identified. If these could be identified, on the basis of such an analysis, it should be possible to forecast weather in the next year or coming two or three years and through this to predict the crop production in the coming year or years.* This then is the third area of study.

A fourth area for study is the delineation of the country into homogeneous crop-weather regions which would enable a closer and more meaningful study of crop weather relationships. Keeping in view the wide variations in the conditions of soil, climate, geography, etc. it may be difficult to expect reasonably accurate relationships to hold good at the all-India level and perhaps not even at the State level or at the level of the thirty and odd rainfall regions into which the country is divided. Even a district which is the administrative and geographical unit may not be homogeneous from the point of view of climate and weather. It is true that the smallest unit for which data on crop production are available is the district. The question arises as to what are the criteria that are to be adopted in delineating the homogeneous regions from the point of weather and crop production. It is not necessary that these regions should be smaller than a district. Perhaps, in some areas, two or three adjoining districts may form a homogeneous crop-weather sub-region.

The data on rainfall, temperature and humidity are also useful for purposes of planning the crop rotations and particularly in

*This question is discussed more fully in Dr. Louis Bean's Paper.

introducing new crops in a given area. One of the distinctive features of the new high yielding varieties programme is that some of the new varieties are of short duration. With intensive irrigation for optimum production, multiple cropping becomes possible; but for planning the appropriate cropping patterns in any area, data are required on likely rainfall and temperature conditions, including hours of sunshine at critical period of crop growth for successful introduction of new cropping patterns alongwith a given idea of the dependability of various weather factors. For example, by substituting the long duration variety of rice by a short duration variety in coastal districts of Andhra Pradesh, it has become now possible to grow cotton in rice fallows. Before the introduction of new crops in an area, the sowing and harvesting seasons of the two crops need to be adjusted and fitted in the weather routine that is observed in this area. It would be necessary, for example, to know what are the chances of occurrence of rain or no rain at the time of sowing and at critical periods of crop growth. Also, what are the likely weather conditions at the time of boll formation for cotton. To take another example, in Andhra Pradesh, cyclones in October-November are a recurrent feature and are known to cause very serious damage to the standing paddy crop. If the behaviour of cyclones or the frequency of occurrence of heavy rainfall in October or November could be studied, it might be possible to introduce a new variety of paddy which could be harvested well before the expected period of frequent cyclones or heavy rains. The loss in production, if any, by growing a short duration variety might be more than compensated by the loss in production in years affected by cyclone or heavy rain. Fortunately, extensive data on rainfall, temperature, humidity, etc. are available in respect of a large number of centres with daily, weekly and monthly frequencies with the India Meteorological Department. These data need to be analysed in close cooperation and association with the agricultural scientists. The Agricultural Meteorologist and the Agricultural Statistician need to evolve suitable techniques for analysis of data so that these could be applied by others before the agricultural scientist could use this information for crop planning. This then is the fifth area of study. The Ministry of Food and Agriculture had in collaboration with the India Meteorological Department made arrangements for supply of daily weather data to selected Agricultural Research Stations to enable them to use this information for purposes of research and evolving new cropping patterns.

There is yet another field where analysis of rainfall and other weather data would be extremely useful to the farmers. It is well known that attacks of certain pests and diseases are highly correlated with the occurrence of certain weather and rainfall conditions. If such relationships could be identified, whenever such climatic conditions favourable for the occurrence of diseases are noticed, the farmers could be given advance warning so that they could apply prophylactic measures to ward off pests and diseases.

There are many such areas where study of crop and weather relationships would be useful to the agricultural administrators, policy makers and planners to the agricultural scientists as well as to the farmers. For example, it has been found that there are possibilities of developing an extension service to the farmers on the basis of the study of rainfall, soil moisture, temperature, dew fall and other factors which would assist the farmers in deciding how much of fertilisers are to be applied and when. Similarly, the study of droughts, areas affected by them and the frequency of occurrence is another very topical and a fascinating subject for study.

The Directorate of Economics and Statistics in the Ministry of Food and Agriculture has been fortunate in having the services of Dr. Louis H. Bean with the assistance of USAID and of Dr. Bernard Oury with assistance from the World Bank to advise on the nature of crop-weather relationship studies that could be organised. A Crop-Weather Relationship Study Unit has recently been set up in the Directorate to devote attention to some of these important fields of study.

It is not yet certain that attempts to study the relationship between weather and crop output would yield results which would enable us to give periodical forecasts of production on an all-India basis. In fact, on the basis of attempts made in the past, some of the Agricultrual Statisticians of international repute voiced a word of caution on dependence on the use of regression models based on weather factors to estimate crop yields. Perhaps, when the studies had been made in the past, the number of factors taken into account were limited by the computational assistance then available. Now with the availability of electronic computors it should be possible to include more variables and use more refined techniques of analysis to establish the relationships and to use them in forecasting the effect of weather on crop production.

Louis H. Bean : Symmetry in Weather and Crop Statistics*

There is to-day no known way to predict next year's weather and therefore no known way to predict next year's crop. This generalisation applies to all countries including India, the United States, Russia, or any other country. The difficulty lies in the fact that meteorological science is still engaged, though more extensively than ever before, in efforts to improve day to day and week to week and in some cases month to month, forecasting.

Statistical devices to meet the need for weather and crop forecasting, such as trend projections and the search for cycles with fixed amplitudes and periodicities have proved fruitless. The net result of these researches is that weather flutucations from month to month or from year to year appear to behave like random numbers, and therefore, for practical purposes, unpredictable.

A review of long time weather and crop data for many countries, and particularly for India, reveals much evidence of repetition in cyclical trends and in patterns of annual variations heretofore generally unobserved, partly because the usual statistical treatment is inadequate to reveal them. While there is very little evidence of repeating cycles of fixed periodicity and amplitude there is evidence of cyclical trends and cyclical characteristics that do appear to repeat. Similarly there is much evidence that shows the existence of repeating patterns of fluctuations in annual data—patterns that repeat with a fixed time lag or interval and that may last for 5 to 15 years before new ones assert themselves. The practical value of this should be obvious.

The more astonishing discovery, however, is that there are points of symmetry, points beyond which the annual variations, and their cyclical trends take the form of the variations just preceding those points, best described by a 180° turn. Another way of putting this is that if 1969 is a point of symmetry the annual variations of 1970, 1971, 1972 and beyond will repeat respectively those of 1968, 1967 and 1966 and so on. For the statistician interested in time series correlations, this means another form of auto correlation *retro* auto correlation in which the lag or time interval is an expanding instead of a fixed one.

There is much statistical evidence that these findings apply not only to weather data for a particular station but also for a weather district, or state or crop areas, or for the country as a whole.

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These findings have already been tested in a limited way in forecasts of weather and crops in a number of districts, states, and for the country as a whole. For example, they gave an excellent advance indication that India's rice crop of 1966 would show very little improvement in spite of reports of an impending return to normal. They indicated a year in advance the improvement in rainfall in India's cereal producing states for 1969 and now provide a tentative hint as to 1970 prospects. They indicate the cyclical reasons for droughts in Rajasthan toward the end of a decade, as in 1968 and 1969, and point to a very low probability of another drought in 1970 and in 1972, but to a greater prabability for 1971 and 1973. They indicate why we have just witnessed the sharp recovery in the October-December rainfall in Madras and why the records for Madras and Akola, for example, carry warnings of dry years some years of the early 1970's.

Agricultural statisticians of India concerned with crop-weather relations, with weather and crop forecasting, with plans to meet the problems of good and bad crop years will probably soon have an unusual opportunity to test and develop the ideas here suggested. Basic data are being assembled to meet this growing need and interest.

The processing of data will provide indexes by meteorological divisions, by states and for the country as a whole applicable to the important crops of each state, and the nation.

To meet these needs, the Office of the Economic and Statistical Advisor of the Ministry of Food and Agriculture under Dr. Sarma, with cooperetion from USAID, is assembling and organizing a large body of historical weather and crop data by districts and states, for use by those interested in weather and crop relations and forecasting. There are additional studies being conducted by the Agricultural Division of the Meteorological Observatory at Poona under the direction of Dr. K. N. Rao with special attention to drought research and efforts to predict final yields during the several stages of the growing season.

Additionally we need deeper probing into what lies behind points of symmetry and their patterns, what is the timing of points of symmetry in both cyclical trends and annual variations, how to identify past and present trends and patterns and how to determine the termination of current pattern and the features of the next one, These and similar efforts could soon put India and members of your Society in the forefront of statistical long-range weather and crop research analysis, and forecasting.

P. S. Sreenivasan, Q. A. Naqvi* and J. R. Banerjee** : *Crop Weather relationship studies* :

A statistical analysis of the crop and weather data which are being collected on two varieties of wheat at Jalgaon and Niphad from 1947 under co-ordinated crop weather scheme was carried out by adopting the linear and curvilinear multiple regression methods. The two varieties are N.P. 4 and Gulab in Jalgaon and N.P. 4 and Vijay in Niphad. The study has revealed the differential response of (*i*) the wheat crop at these two stations, (*ii*) the varieties at the same station and (*iii*) the N.P. 4 variety at these two stations.

The difference in gain in information by resorting to the curvilinear technique instead of the usual linear multiple regression is brought out for these two stations.

The effect of rainfall distribution in the fifty-two weeks of the year commencing with January on the wheat grown in the winter months of November to February at the two crop weather stations namely Jalgaon and Niphad is investigated with the help of data extending over a period of 22 years commencing from 1947. The rainfall response curves obtained by using Fisher's well known method of regression function do indicate that by and large these curves for both the varieties of wheat at these two stations show similar pattern of response both before and after removing the slow progressive changes and the multiple correlation is of the order of 0·8.

In general there is a positive response to an additional unit of rainfall in any week but the magnitude of response is more for the additional rainfall after sowing and during the summer months. These results are not in agreement with the findings of the earlier workers who have made use of rainfall for thirteen weeks commencing with the last week of October (Standard weeks number 43).

Cotton is one of the main rotation crops in Jalgaon district and is grown as a Kharif (monsoon) crop. In this paper, the influence of rainfall on the yield of cotton grown in the Government experi-

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mental farm, Jalgaon, under crop-weather scheme ever since 1947 has been statistically analysed by adopting Fisher's response curve technique. Rainfall in all the 52 weeks of the year has been taken into consideration. Unlike rabi wheat, by this technique the multiple correlations are of low magnitude being 0·67 before removal and 0.55 after removal of progressive changes in the variety Jarilla and 0.42 before removal and 0·36 after removal of trend in the variety Virnar.

The strong negative response of yield of kapas to any additional rainfall from the beginning of the year to the end of July becomes reversed for the period middle of January to middle of May when the progress changes are removed for the yield as well as the six distribution constants.

The crop growth and yield are governed to a large extent by the weather complex. Even for any one weather element, there is an optimum value in which the maximum response takes place and this response continuously decreases with values either above or below the optimum and ceases when the higher and lower threshold values are reached. In this biological phenomenon, the change in the rate of decrease with the increase or decrease from the optimum value may perhaps be evaluated by fitting curvilinear multiple regression curves. In the absence of any information from experiments carried out in controlled chambers, it is not possible to state (*a*) the rate of change in response as one moves away from the optimum value, (*b*) the amount of asymmetry in this change on either side of the optimum and (*c*) the threshold values.

There are various problems arising out of the fitting of Fisher's response curve to crop-weather data. Some of the more important problems are :

(*a*) the optimum width of the subdivisions,
(*b*) the length of the season,
(*c*) the length of the data and the degree of the polynomial and
(*d*) the effect of change in the starting point of the season.

J. C. Das : Forecastiag Yield of Principal Crops in India on the Basis of Weather—Paddy/Rice*

Regression equations have been fitted for issue of monthly forecasts of yield of paddy/rice on the basis of weather parameters during Kharif season for homo-climatic regions, *viz.*, Sub-Himalayan

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West Bengal, Coastal Andhra Pradesh, Tamil Nadu and Kerala. It is noticed that the average yield per acre in all these divisions had increased due to technology from early fifties. There was also increase in the average yield during 1906 to 1920 in Coastal Andhra Pradesh and Tamil Nadu due probably to steady increase in acreage of irrigated lands. It is found that the number of rainy days during the period 16th September to 15th October and mean maximum temperature during 16th August to 15th September have significant effect on yield in Sub-Himalayan West Bengal. In Coastal Andra Pradesh, the number of rainy days in July and October and distribution of rainfall in August and September are highly correlated with yield. Rainfall in Western Ghats area during the period 16th May to 31st May and 16th June to 30th June affect the yield in Tamil Nadu. In case of Kerala, rainy days during the period 16th April to 15th May and the occasions of drought and flood during the period 16th June to 31st August, contribute significantly to the yield.

All correlation coefficients obtained except for Sub-Himalayan West Bengal are significant even at 0·1 per cent level.

The formulae have been tested for the later years 1965 to 1968 and the expected yields compare with the actuals within 5% in the seventy-five per cent of the cases and within 10% in all the cases.

The subject of drought conditions has assumed considerable importance specially in recent years and the present study is a part covering certain aspects of this problem. Studies for other areas are also in progress.

J. P. Dubey: Weather Indexes: A Review of the Methods of Constructing Indexes of the Effect of Weather on Crops*

It is often felt necessary to decompose the numerous meteorological variables in one or at most a few composite variables in the form of index numbers, which could be conveniently handled in the production or supply equations. Temperature and rainfall are the two most important factors affecting crop yields. But both of these change so very frequently and suddenly that short period observations are required to be considered for their effect on yields. It may be found that weekly rather than seasonal or even monthly observations on rainfall are more revealing. It is difficult to include the individual weekly rainfall data and weekly mean temperature as such in an equation that has other explanatory variables also in it.

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Often the time series is too short to accommodate more than a few variables. Attempts have been made by many authors to solve this difficulty by constructing different types of indexes which could be used instead of the numerous meteorological variables.

Wichard suggested a moisture temperature index as a measure of the combined effect of the two variables on yield. This index is given as the difference between the rate of change in yield per unit change in temperature and the ratio of total rainfall and total evaporation during a particular crop period. Lange, assuming that the effectiveness of rainfall is directly proportional to total precipitation and inversely proportional to mean temperature, suggested a simple formula $I=P/T$. de Martonne made an improvement in the Lange formula by adding 10 to the denominator to avoid getting negative values of I. Koppen suggested three other modifications *viz.*, $I=8p/15T+120$; $I=2P/T=3$; and $I=P/T+7$.

In order that the formula conforms with the vant Hoff's law of doubling of growth for each rise of 10°C in the temperature, Angstrom gave the formula as $I=P/I.07T$.

Oury suggested that a weather index which he called as the aridity index could be computed with a comparable scale using monthly precipitation and average monthly temperature for n months thus :

$$I=\sum_{i=1}^{n} (P_i)\ 12/n \div (\sum_{i=1}^{n} Ti/n)+I0)i=1, 2,..., n\ t=1, 2, 3...n$$

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

Thornth Waite also suggested an index based on moisture ratio which can be given as the ratio of the difference between precipitation and potential evapotranspiration to potential evapotranspiration, *viz.*, $M=P/e-I$. Potential evapotranspiration can of course be measured only experimentally and such measurement requires complex technique.

Hypothesising that the meteorological variables are a weighted function of time, Ram Dayal and J. P. Doll 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, which can be used as an explanatory variable in yield equations. Thus if coefficients of the periodical variables are a linear function of time, the variables could be collapsed into a single variable. If the function was quadratic they could be collapsed into two composite variables. Here we face some problem. If the number of such composite variables is more than one there will be perfect multicollinearity among them and it will be difficult, rather impossible to estimate their separate effect. Secondly, if the yield equation was a quadratic or some other higher degree function of the composite meteorological variables, the number of variable in the yield equation will be further increased, nullifying the advantage gained by collapsing the periodical observations. The composite variable can be made into a weather index so that whatever be the number of the composite variables, the same can be reduced to one variable *i.e.*, the index number series constructed from using the means of the periodical observations as the base. Thus if $Xtj(s)$, $wtj(s)$ were taken to mean respectively, the periodical observations as year t and season s, and the weights assigned to them, yt the yield ; we have

$$yt=f(zt)$$

where
$$zt=\sum_{j=1}^{k} ztj$$

and
$$ztj=bi\times tj=wj(s)\times tj(s).$$

Index number It will be given by the formula

$$It=\frac{bizt-b_2z^2t}{bi\bar{z}t-b_2z^2}$$

if the function was quadratic and

$$It=\frac{bzt}{b\bar{z}t}$$

if linear.

Shaw and Stallings separately constructed their weather indexes not from the periodical weather data but from the yield data. These indexes are based on the ratio of actual yields to the trend yields. The trend used could be linear or higher degree polynomial or some type of moving average. Data used in the construction of these indexes are taken from experimental stations where reliable yield figures can be available. Perhaps one could also use the aggregate output or average yield data for a state or a country in a like manner to construct the weather indexes.

Merits of the last two methods of constructing the weather indexes are yet to be fully explored.

Dr. L. A. Ramdas : "Fundamental Facts of Crop Growth in relation to Environment: Precautions to be kept in mind in attempts to establish Crop-Weather Relationships by Statistical treatment of data"*

The radiation emitted by the Sun extending throughout the spectrum from the shortest X-rays through the ultra-violet, the most intense visible region and beyond into the infra-red and further into the longer radio waves, provides the warm environment so essential for sustaining all forms of life on our planet. Minor constituents in the upper atmosphere, like atomic oxygen and ozone fortunately cut off all the lethal X-rays and ultra-violet radiations by absorption. The presence of water vapour, carbon di-oxide and ozone which absorb in their characteristic absorpotion bands in the infra-red region of the spectrum and also re-radiate in the same wavelengths, ensures an effective "blanketing effect" preventing the earth's surface and the adjacent air layers from cooling too rapidly by radiative exchange during night time. Lastly, the accident of the Earth's 22½ degree tilt with respect to the ecliptic blesses us with the wonderful march of the Seasons.

Another very vital part played by the Sun is in bringing about "Photosynthesis", that wonderful progress by which the green colouring matter (chlorophyll) of plant leaves absorb certain rays of the Sun in the visible region and synthesise, from carbon of the carbon-dioxide of the atmosphere and the water present on the leaves, all the carbohydrates constituting the dry matter of the plant. By and large, there is more than enough of solar radiation needed for photosynthesis but the carbon-di-oxide may, perhaps, be sometime a limiting factor.

Equally with Sunshine, Water is also a most vital need of plants throughout their lifetime, the quantities required for enabling the plant root system to extract water and nutrients from the soil to maintain the continuous upward flow of sap right upto the plant leaves, depending on the growth phase of the plant.

Agricultural crops being seasonal, the total period of growth from sowing to harvest lasts only for a few months, extending up to a year or beyond only in exceptional cases like sugarcane.

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The water needed by plants comes from rainfall during the rainy seasons and water stored, whenever and wherever possible, during rains for use as irrigation during dry spells. During wet spells there is often too excessive a downpour and the excess water drains into water channels and thence into the larger river systems. The fraction of the precipitation held by the top few feet of the soil is the only fraction of rain or irrigation water that is ultimately available to growing crops. The water that runs off or is evaporated from the bare soil plays no part in supporting plant growth unless it is stored and fed into agricultural fields later as irrigation.

During sowing time the surface layer of the soil should have enough moisture to promote germination. After germination, the plant begins to put forth its branches, tillers and foliage and soon enters the next most important phase of its grand period of vegetative growth when water requirement is maximum. At the end of the grand period comes the next phase of flowering and seed setting, maturing and ultimately the harvest. During the vegetative phase, spells of rain or irrigation should be punctuated by clear spells with sunshine to promote optimum growth. If the rainless spell extends too long it develops into a drought during which the plant does its best to send down its root system into deeper soil layers which may have enough moisture. Should this resource too fail, the growth stops, the plant wilts and may die. Even at this stage, if a timely rain or some irrigation water is made available, the plant revives wonderfully fast and if the wet spell continues, the plant makes up for all the lost growth and may even put forth a bumper yield : such is the adaptability of the living plant which no mathematics or statistics can simulate.

It is well known that it is not the total rainfall but its distribution week by week during the life-time of the crop that controls its growth and well-being. Too much water leads to water-logging and stifling of the root zone. Too little is also dangerous as mentioned above. What is needed is an optimum distribution during the life of the crop. The reproductive phase associated with flowering, seed setting and maturing needs conditions that favour fertilizing of the flowers and less rain or irrigation than in the earlier phase and enough clear sunshine to ripen the seeds before harvest.

Living plants thrive best at an optimum temperature of about 30 to 35°C. The environmental temperature is conditioned very much by the micro-climate which in turn depends on the heat and moisture balance of the plant community as determined by the disposal of the incoming solar radiation.

Below freezing point killing frost sets in : a major risk to agriculture. Temperatures approaching the upper lethal temperature of 45°C or more on the other hand, cause whole-sale withering and total failure of the crops. A healthy standing crop itself provides a shielding from the heating effects of solar radiation. Thus, in a sugarcane crop, for example, particularly after it has developed a canopy in the later stage of crop growth, there is effective shading of the lower parts of the plants as well the ground below. The air inside the crop, therefore, is considerably cooler and more humid than the air above a bare ground in the neighbourhood.

A plant community responds best to certain "optimum" values of the various environmental factors controlling its well-being during the growing season. *"Too much" is as injurious as "too little"*.

The new Division of Agricultural Meteorology started at Poona in 1932 directed its organisational and research activities for the next two decades or more.

A critical examination of the then available series of crop and weather carried out within the first three years of the formation of the above Division revealed that the crop yield data published district-wise and for a long series of years, recorded as they were for revenue purposes on the basis of mere eye estimates, were too inaccurate for scientific analysis. The climatic data too had been obtained for general weather forecasting from a net-work of Observatories situated in non-agricultural or urban surroundings. It vas, therefore, decided to start a fully equipped "Central Agricultural Meteorological Observatory" at the farm of the Agricultural College, Poona to initiate the necessary investigation of the micro-climates of the typical crops and to evolve techniques for securing accurate estimates of the periodical developmental or growth observations of selected crops during their entire life-time by employing the random sampling techniques, following the trail blazed by the pioneering work of Dr. R. A. Fisher and his colleagues at Rothamsted. These preliminary researches at Poona provided an excellent basis for evolving the All India Co-ordinated Crop Weather Scheme for ushering in a new era of precise periodical observations on the growth and development of crops in selected fields year after year at a net-work of Crop-Weather Observatories situated at important Experimental Farms in the different States of India. The present writer had the opportunity to show

Dr. Fisher the work of our Divison at Poona and to discuss with him the entire Crop-Weather Project before its initiation. He was so enthusiastic about the project during his 1939 visit to India that he recommended its urgent commencement both to the ICAR and to the then Viceroy of India.

Preliminary work to obtain the enthusiastic co-operation of the States of India, to set up the Crop-Weather Observatories at the selected Experimental Farms, train the observational staff provided by the States in recording the crop developmental and weather data, to organise the supervisory and computational staff at the headquarters of the Scheme at Poona, etc., were completed by 1946-47 and the full Scheme began operating from that year under the auspices of the ICAR, the Indian Central Sugarcane Committee and the Indian Central Cotton Committee. The details of this important scheme, in outline, will be found in Chapter III of the Monograph on "Crops and Weather in India" by the present writer (ICAR-1960) (In the earlier chapters of the same publication will be found a summary of the researches in Micro-Meteorology referred to above as well as an account of another major service to agriculture, *viz.*, the Weather Service for the Farmer initiated soon after World War II, in the evolution of which the present writer had played some part).

The Crop-Weather Scheme has ensured that reliable and full details of the growing crop and its environment are collected according to a standard plan. The wealth of information has been flowing regularly into the Agricultural Meteorology Division at Poona for more than two decades now.

Reference may be made to R. A. Fisher's famous, classical, paper in which he has enunciated the method of fitting 5th degree orthogonal polynomials to represent the march of each of the series of seasons under consideration so as to represent each rainy season (in 5 day rainfall figures in his case) by smooth curves which provide, yearwise, a series of sets of six distribution constants. The slow or long-term variations or trends exhibited by these constants is again eliminated by the polynomial technique. Similar 5 h degree polynomial curve is fitted to the series of yield data and the smooth variation of yield accounted for by this curve. The departures frcm this curve, representing the random part of the fluctuation of yield depending on the year to year fluctuation of the season are predicted separately. Reference may be made to another classical paper by R. J. Kalamkar and V. Satakopan in which they have illustrated the

Fisherian technique to the case of cotton yield data at the Experimental farms at Akola and Jalgaon. From table VII of their paper it will be seen how out of the 27 degrees of freedom (27 years' data), 11 degrees of freedom are lost to "Regression" and the "Polynomial" and only 16 degrees are left for predicting the yield. Further, as pointed out by all the above mentioned authors in their respective papers, the end values of the polynomial do not give any indication of the trend in the next year or years.

If now one considers additional factors like "Temperature" during the growing season, for each such additional factor there will be a loss of 6 more degrees of freedom and less will be left for prediction of the future yield. At present, the series of crop-weather data under the Scheme run to 20 or 22 years for each station. One may endeavour, provisionally, to build up artificially longer time series for preliminary study, by combining the data of neighbouring stations that may be situated in the same climatic zone, though this is not strictly correct. Such provisional attempts are, no doubt, being attempted by the Agricultural Meteorology Division at Poona ; such complicated statistical analysis is facilitated by the more rapid computing machines of the present. As mentioned earlier, much caution is necessary in accepting premature conclusions provided by such hurried studies.

It seems appropriate now to take up the query posed by the heading of this section. It will generally be admitted that the growing plant is a very efficient "integrator" of the many sequences of contemporary weather that it has experienced up to the particular stage of its growth. As we already have the detailed growth history of the crop at each centre from the detailed developmental data recorded week by week, it should be an easy matter to examine the relations between the crop's growth factor at any stage and the subsequent yield which is also known accurately. Thus we have successively data relating to :—

(*a*) Germination Count, (*b*) Main plant and its tillers, (*c*) height of plants during the period of vegetative growth, week by week, (*d*) details of flowering or earheads, etc., and finally the actual yield.

Attempts to explore the possibilities of predicting the yield from earlier indications or growth factors will, I think, be very rewarding.

The above mentioned studies must go on urgently while the Fisherian technique to predict the yield from the climatic sequences also proceeds unabatingly.

K S. Krishnan and C. L. Malik* : On Statistical Techniques for the study of Crop-soil-weather and water relationships.*

Agricultural production is determined largely by three principal groups of factors, namely soil, weather and technology. In primitive agriculture the first two groups had the dominating effect on crop yield. In advanced agriculture, technology plays an ever increasing role in stepping up production. Modern advanced technology is supposed to be capable of providing a tailor made solution fitted for each soil weather complex. In influential circles an opinion is gaining currency that studies on crop weather relationship is not likely to lead to any useful result in the context of rapid change now being brought about in agriculture. That this is not correct can be illustrated by a few facts :

(*i*) The level of technology adoped in the corn and wheat belt of U.S.A. is very high and bulk of the water needs of these crops there are met by the melting ice. Yet in some years crop losses of over 10 per cent are reported due to unfavourable weather conditions.

(*ii*) In India for implementing an intensive agricultural development programme, popularly called the Package Programme, a group of 15 districts were selected about 8 years back and these districts were considered relatively free from weather and other natural hazards. During the years 1965-66 and 1966-67 the production of total food-grains in these districts sharply fell by 21 per cent and 15 per cent respectively compared to 1964-65. In some of these districts the fall was as much as 50 per cent or more in one of these years.

(*iii*) Out of the total cultivable area of 194 million hectares and cultivated area of 155 million hectares in the country, only 36 million hectares enjoyed irrigation facilities in 1968-69. According to Dr. S. R. Sen, Vice-Chairman of the Irrigation Commission, even after all possible irrigation sources are exploited (and that is likely to take several decades) the maximum area that can be irrigated is 82 million hectares

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about half of which will be heavily dependent on the monsoon and therefore not fully assured. Therefore as much as 112 million hectares, *i.e.*, 58 per cent of the cultivable area in the country will continue to depend fully and another 40 million constituting roughly 20 per cent of the cultivable area-partly, on rainfall even in that distant future.

(*iv*) It is however true that by applying modern techniques like drip irrigation a near miracle has been performed by raising fruit gardens in arid areas of Israel with only 2″ of annual rainfall. But adoption of such technique on a scale required by our country is prohibitively costly.

The above facts indicate the need for undertaking intensive studies on crop-soil-weather and water relationship. Such studies should be considered as an essential supporting activity for agricultural development. However the contribution of technology, current and potential, should be taken into account in planning such studies and interpreting the results obtained.

Within each of the three broad groups of factors influencing the yield, namely, soil, weather and technology, a large number of factors can be identified. The effects of these factors on yield can neither be considered as independent nor as additive. Alternative scales of measurements such as linear, quadratic, logarithmic, etc., which are possible for each factor further increases the complexity and the number of potential variables.

That the effect of a single factor like rainfall during the crop seasons might differ considerably in approximate areas can be illustrated by the yield data recorded in crop-cuts conducted in West Godavari district during the past 7 years. The district was divided into four agro-climatically homogeneous areas and estimates of yield rates of first crop rice was worked out for each year separately for each area. Not less than 50 crop cuts were harvested in each area in each year. The results are presented in the chart. It may be seen therefrom that in Areas-I and II lowest yield rates were obtained in 1962-63 followed by 1964-65. On the other hand in Area-IV these were the best two years of production. Again very poor yields were recorded in Area-IV during the years 1965-66, 1966-67 and 1968-69. These were years of relatively good yield performance for Areas I and II. An examination of the causes for the same revealed that in Area-I and II enjoying good irrigation facilities drainage was a serious problem which depressed the yield in years of good precipitation. On the other hand Zone-IV is an upland area with poor irrigation facilities but free from drainage problem.

The most common technique used for studying the individual and conjoint effects on a number of so-called indepedent variabes on a dependent variable is the fitting of partial regression equations and working out of multiple correlation coefficient. The square of the multiple correlation coefficient provides an estimate of the fraction of the variation in the dependent variable that can be ascribed to the total effects of the independent variables. In a classical example, Fisher tried this technique on a set of comparable data collected during the period of over 60 years. Subsequently many research workers, particularly in India, have spent a lot of time and resources to apply this technique on short run data extending over a period of 20 years or less. With 20 years' data and 6 independent variables, to establish significant difference from *zero*, the observed value of R^2 must be as high as 0·57. Even if a value of R^2 higher than this is obtained, the partial regression coefficient of the equation fitted are unlikely to be of requisite precision to serve as indicators for prediction.

Such exercises however can be put to one important use, namely, to compare the relative influence on yield of one set of variables in toto with that of another set. Two such useful results obtained in the course of studies undertaken at IARS on the long term data recorded at IARI were as follows :—

(*i*) In respect of rainfall, minimum temperature as well as maximum temperature, distribution constants based on the entire weekly data during the period October-April were together having weaker linear relationship than similar distribution constants based on the period January-April.

(*ii*) Where the values of R^2 for the distribution constants based on rainfall, minimum temperature and maximum temperature are moderate distribution constants derived for a composite index of these factors on the lines suggested by Angstrom gave a stronger relationship with yield.

Another approach made for studying the problem is the estimation of water requirements of crops under a set of normal conditions and to evaluate the changes needed in the irrigation schedule based on the precipitation from time to time. Estimates of moisture loss due to evapo-transpiration might be useful in this connection.

In recent years the International Minerals and Chemicals Corporation of the U.S.A. have introduced in a customers' advisory service a technique called 'Weather Model' for adjusting fertilizer use and other agronomic practices according to the expected soil moisture and soil temperature at the root zone of the plants in periodic intervals. "The prediction equations developed by them are however not applicable to tropical climate since the major source of moisture in the areas covered by them is from the melting of ice. Further the detailed types of data used by them are not readily available at present in our country.

To sum up it would appear that the problem deserves intensive research for the development of appropriate statistical techniques.

R.S. Chadha : Assessment of the Effect of Wheather on Crop Yield*

Plants and crops are greatly dependent on weather during the growing season, particularly during the critical phases like germination, flowering, maturing, etc. For healthy growth and good yields of crops certain optimum conditions of rainfall, wind, sunshine, temperature, humidity in the air and upper layers of the soil are necessary. The march of climatic factors is by no means smooth and regular as might be suggested by their normal values. In any single year these factors deviate at random and in varying degrees from the normal values. The prolonged droughts of 1965-66 and 1966-67 in large parts of the country brought into sharp focus the need for research into the effect of various weather factors on crop production.

Since the advent of planning, a large number of dams and reservoirs along with a variety of minor irrigation sources have been built. Still irrigated area under crops is at present only 1/5th of the total cropped area in the country. In view of the need for timely availability of water at different stages of crop growth, rainfall is the most important single factor affecting plant growth and crop production. The distribution of rainfall in India is determined to a large extent by the physical features of the terrain and the location of the mountains and plateaus.

At present comprehensive data on daily, weekly, monthly and seasonal rainfall are published by the India Meteorological Department for individual stations, districts and rainfall regions. It has been

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observed that there are considerable variations in the amount of rainfall received within a district or a region. As such a single average for the district or region can sometimes give a misleading picture about the spatial distribution of rainfall within the district or region. Further there are wide variations in the amount of rainfall received within a crop season in a particular area. The total amount of rainfall for a season cannot, therefore, give any positive clue to the level of yields in a particular region. However, for purposes of assessment of the effect of weather on crop yields and for forming an idea of the size of the crop at different stages of growth, it is necessary to study the lessons of past meteorological history at different levels. An all India indicator of the effect of rainfall on the yields of individual crops would be quite helpful to administrators, planners and policy-makers. An attempt has been made in this paper to evolve rainfall indices for different crops and groups of crops.

Agricultural year is divided into four rainfall seasons, *viz.* South-West Monsoon (June to Sept.), post-Monsoon (Oct. to Dec.), Winter season (Jan. to Feb.) and Pre-Monsoon (March to May). A very large percentage of the annual rainfall over the country occurs during the South-West Monsoon season. On the basis of the soil and climatic conditions suitable cropping patterns have emerged in different areas. Naturally, the rainfall in different seasons will not have the same importance in all the areas of the country. As such for assessing the effect of rainfall on the production of a crop, only those regions/States should be taken into account where this crop is grown in a particular season.

By taking normal rainfall as hundred, rainfall indices have been worked out for each State for each of the rainfall seasons for the period 1950-51 to 1969-70. South-West Monsoon and Post-Monsoon are important for the sowing and growth of rice crop. The rainfall indices for 9 States accounting for about 90% of the total production of rice, for the South-West Mansoon and Post Monsoon season have been worked out by weighting the individual State indices by the production during 1964-65, which was a normal year. Similarly, for wheat, all-India rainfall indices have been constructed for Post Monsoon and Winter seasons by combining the rainfall indices for 6 States accounting for 92% of the all-India production of wheat in the country. For foodgrains as a whole, all-India rainfall indices for each of the four seasons have been constructed by taking 12 States accounting for about 90% of the total production of foodgrains in the country.

It has been observed that rainfall indices for the major rainfall seasons may not be quite helpful in gauging the effect of rainfall on the yield of certain individual crops. It is, therefore, proposed to have separate indices for autumn, winter and summer crops of rice, kharif and rabi jowar and so on by taking into account the periods of field preparation, planting, growing, tillering and harvesting. Thus, the periods for which indices would be constructed for particular crops and states would be quite different from the four rainfall seasons for which indices have been presented so far. After the construction of rainfall indices for different periods and crops, it is proposed to correlate yields with these indices to enable to (*i*) an assessment of the effect of rainfall on the yields of individual crops, and (*ii*) providing a basis for—forecasting of crop yields at different points of time during a crop season.

It would be seen that we are still in the preliminary stages of developing a suitable rainfall index and considerable work has to be done before we can say with confidence that this method would provide a reliable basis for assessment of the effect of rainfall on crop yields.