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RESEARCH ARTICLE

CROP-WEATHER MODELING: A REVIEW OF EVOLUTIONARY TREND OF METHODOLOGY

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ABSTRACT

The weather factors (rainfall, temperature, soil moisture, snowfall and so on) like other inputs such as land, labor HYVs seeds, irrigation, fertilizers, pesticides etc. are also a direct input in crop production. Moreover, in a state of backward agriculture where the technological adoption and diffusion is very slow or near nil, the weather factors count more than other inputs because of their direct and indirect effects. Again understanding the precise link between weather and crop yield could have some implications for the effects of climate change on food supply and crop management policies. So it can facilitate some kind of institutions that can secure the crops from the vagaries of monsoon. Thus, the study of crop-weather relation is of immense help to the policy makers, agricultural scientists, agricultural economists and meteorologists alike. The present study here attempts to review the works done both in India and abroad which brought an evolutionary trend in weather-crop modeling. The objectives of study are: (i) to bring out the evolutionary trend that the weather-crop analysis has gone through in evolving itself into a more fine-tuned and sophisticated area of research which gradually makes it more close to reality and (ii) to point out some loopholes that are still existing in past studies.

INTRODUCTION

The debate on cause and effect relationship between weather and crop production has been an exhilarating area of research for different research communities like the agricultural scientists, meteorologists and agricultural economists. In western economies, the study of weather crop relation in a systematic manner started a century ago while in India it was initiated less than six decades ago. In India, the precise and deliberate attempt was made in 1945 when Indian Council of Agricultural Research (ICAR) launched the 'All India Coordinated Crop Weather Scheme' (AICCWS) data (Kainth, 1996). The agricultural economy of India with its largely growing population is closely linked with weather, in particular the monsoon. So, under the scheme of AICCWS, several meteorological observatories were set up throughout the country and systematic data on weather-crop relation for rice, wheat and jowar were recorded. Thus, Indian Meteorological Department (IMD) was the first to study this relation. However, the systematic recording of data meteorological departments on different climate factors on the observatory plot with controlled experiment holds less relevance for the agricultural economy. This is because the weather is really uncontrollable which affects the crop production at various stages. One of the objectives of the study on weather-crop relations by agricultural economists is forecasting of crop production in advance. For forecasting of crop production, we need to have both forecasting weather by meteorological department, and the uncontrolled and real cause-effect relationship between weather and crops. Thus, agricultural economists' study on weather-crop relations requires both controlled and uncontrolled data. Economists' interest in the study of crop-weather relation is of relatively recent origin. It has been realized that the effect of weather needs to be taken out of the observed behavior of the yields before analyzing the contribution of other inputs and technology (Vaidyanathan, 1980). Apart from this, there are some other reasons for which the researcher needs to have a priori information about weather-crop relation. First, the researcher should be in a position to describe and roughly classify the characteristic states of the weather occurring from year to year in the region of his study so that he will have some idea about the state of weather affecting the farms in his sample study. Secondly, some indications or haunches will be available to him regarding the types of land that are likely to be vulnerable or benefited from a particular state of weather. On the basis of this information, some policy formulations can be made to boost or save the crops for the farmers as they can adjust their use of certain inputs according to the weather condition. Thirdly, knowing the precise link between weather and crops could have some implications for food security, food supply management and overall growth of the economy.

Keeping the above mentioned important points in view, the present paper reviews some studies done in both India and abroad. Although the review does not claim to be comprehensive and extensive, it covers many studies

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conducted by economists, agricultural scientists and meteorologists. This study also takes the help of two earlier studies Ramdas and Kalamkar (1938) and Vaidyanathan (1980) in citing some of the past studies so as to maintain the continuity of the process of revealing the evolutionary trend of methodological development. However, the specific objectives of the study are: (i) to bring out the evolutionary trend that the weather-crop analysis has gone through in evolving itself into a more fine-tuned and sophisticated area of research which gradually makes it more close to reality and (ii) to point out some loopholes that still exist in past studies. The study is organized as follows: after giving a brief introduction, the second section touches the concerns of weather in agriculture production. The third section briefly discusses the need for such a survey. The fourth section deals with the survey of analytical studies based on usefulness of weather variable for different purposes. Fifth section is on the review of weather ex-post production phenomenon, followed by the review on the weather in crop forecasting in sixth section. The review on weather in supply response analysis is in the seventh section. Eighth section is on the trend estimation review. The limitations of the researches done earlier are highlighted in ninth section and finally it ends with concluding remarks.

II. Concern of Weather in Agriculture Production

The production of crops in any region is a function of two sets of factors, i.e., controllable and uncontrollable. The controllable set includes the directly measurable inputs such as seeds, fertilizer, pesticides, land (acreages), irrigation and other infrastructural facilities (technology). The uncontrollable set includes the various climatic factors like rainfall, temperature, humidity; run of dry days, day length etc. These are controlled by nature and considered exogenous to the production function. The variation in production due to these uncontrollable exogenous factors sometimes outweighs the contribution of controlled variables leading towards an unstable crop production. The weather factors like rainfall and temperature affects differently at different stages of crop growth. At some stages, it becomes conducive while at other stages it is harmful. The sufficient rainfall leads to more acreage at sowing period while it leads to more yield at growing stage. Similarly, temperature also has different impacts. However, man can influence the process of natural factors influencing production through technological advances. The variables currently exogenous can be made endogenous through human skill and knowledge, but the scope is very little. We can make the transformation practically and theoretically on an experimental plot where these factors can be strictly monitored. Nevertheless, it is too difficult to pursue such a process when thousands of acres of land are involved in production process. The controversy involving agronomists & meteorologists and agricultural economists is that agronomists and meteorologists always tend to view weather as the dominant factor-influencing yield and acreage behavior of crops while agricultural economists look at technology and other measurable inputs level (Offutt et al., 1987). However, the weather, like other inputs such as HYVs seeds, fertilizers, pesticides etc. is also a direct input to agriculture. More specifically in a state of backward agriculture where the technological adoption and diffusion is very slow or near nil, the weather factors count more than others because of their direct and indirect effects. Again understanding the precise link between weather and crop yield could have some implications for the effects of climate change on food supply and crop management policies. Therefore, it can facilitate some kind of institutions that can secure the crops from the vagaries of monsoon.

III. Need for the Survey

The application of statistical methods to crop-weather analysis started in India in 1909 by Sir Gilbert Walker (Ramdas and Kalamkar, 1938). Thereafter, many experts from different but interrelated professional communities enriched the theoretical as well as empirical literature on this very area in due course of time as we have experienced and empirically verified that still weather is playing a more prominent role in agricultural production, although the use of modern techniques is there in place since 1960s in India. The meteorologists, agronomists and agricultural economists, looking at different aspects of 'weather' influencing directly or indirectly the crop production have put their efforts to make the analysis more polished up and the results more close to reality. Few studies (like Ramdas and Kalamkar, 1938; Vaidyanathan, 1980) showed the survey of literature in this vital area of research in different contexts[1]. Nevertheless, an important point of departure of present study from the existing literature lies in its wider coverage and more comprehensive understanding of the theme about crop-weather modeling. This study reflects the methodological evolutionary trend that occurred through passage of time. Those existing studies dealing with the review of literature in this area are narrower in the sense that they only reviewed the works done in India citing the results only and somewhere the methodologies used by them. However, they did not tell the evolutionary trend of the methodologies. Thus, the present study is different from those past two studies in that aspect as it is mainly concerned with Indian research but at the same time it cites the major studies in abroad contributing to the sophistication of methodology. It also tends to find out the limitations of all the existing methodologies and attempts to give points for the future research. Thus, it is an improvement over the previous works.

IV. Analytical Work on Crop Weather Relation

Different methods have been experimented by taking weather as a variable by researchers for different purposes. Here, weather includes sometimes rainfall, temperature or both or a composite index of both called weather index. However, Stalling (1960, 61) has pointed out three important uses of weather in crop modeling in his pioneering work on 'weather index' as follows: First, one uses weather in the supply analysis for individual and groups of commodities. An important need in supply analysis is for a variable to account for the variation in yield or output due to weather. Second, the researchers want to take out the effect of weather on yields and production before further study of other variables. Third, there is also a need for a measure of influence of weather for individual years for an informal explanation of ex-post production phenomena. Besides these uses, weather is having a great deal of usefulness for advance forecasting of food grain production after adjusting for level of technology adoption. Because of those uses, we have reviewed these

[1] There is a comprehensive bibliography on crop weather relationship compiled by Despande (1980).

studies under different sub-heads in line with that classification and keeping the idea in mind of presenting the evolutionary trend that has taken place in due course of time. Different functional forms have been shown to make the analysis more explicit.

(i) Early Indian Studies

As Ramdas and Kamalakar (1938) mentioned in their study that Jacob was the first Indian to apply statistical methods to study the crop-weather relation. In his two papers, the time they were published is not mentioned; he used the correlation coefficient between the acreage and rainfall over the period of nineteen years in the first paper and 29 years in the second paper for Punjab region. Rainfall in different months was found to be slightly beneficial. Unakar (1929) also used the same methodology in case of Wheat in Punjab.

Ever since after these three studies, the methodology was slightly fine tuned and people started using linear regression model where weather parameters like rainfall and temperature are regressed on crop yields along with other variables comprising direct inputs to agriculture. Using the same methodology, Kamalakar and Satakopan (1935) studied the effect of rainfall of sowing season and prices prevailing in the pre-sowing season on cotton acreage in eight districts of Bombay presidency. They stressed much on weather and market because of the idea that weather condition during sowing season has its reaction on acreage since certain types of weather condition may be considered suitable for a particular crop. Market price, on the other hand, has its reaction on acreage by influencing the mind of cultivator as to the most profitable way of allotting his land to different crops. Many studies applied the same methodology while studying the impact of weather, in particular, rainfall but the only difference was that sometimes they took acreage or yield as the dependent variable (Kamalakar and Rao, 1935; Narashimham & Ramdas, 1937; Rao, 1936).

(ii) Further Development in Methodology

One cannot but be impressed by the care and imagination which evidently went into the design of crop weather observation. A large number of information was collected in various meteorological stations for the period of five years to twenty years on different weather variables under the scheme of AICWS in India. That led to the spectacular improvement in the methodology of crop-weather modeling. In the early 1960s and 70s, various Meteorological Departments of India produced many papers on crop-weather relations that were really distinct from the early Indian studies of 1930s and 40s with regard to the methodology used, i.e., in multiple regression model, weather parameters taken into account like rainfall, number of rainy days, temperature (both maximum and minimum and mean of two), sunshine and humidity etc[2]. Some of the works like Mallik (1958) examined the nine years data for three crops of wheat, Jowar and cotton. He concluded that the wheat yields are very low due to rust attack because of the fact that the number of hours of bright sunshine days during November was abnormally low. From this, he also went on to conclude that unseasonal rains and cloudy conditions created conducive atmosphere for severe rust attacks. In other papers, Mallik (1958, 1960) used the same procedure and found the significant effects of different meteorological variables at different time periods.

(a) Studies Using Fisherian Regression Integral

Some attempts were made to use the 'regression integral technique' developed by Fisher (1924) for analyzing the crop-weather relation. Some early Indian studies like Kamalakar and Satakopan (1935), Nair and Bose (1945) also applied this technique. But after the scheme of AICWS came to existence, many studies started using this technique taking the advantage of the sophistication initiated in collection of data. The studies like Acharya et al. (1960), Gangapadhyay and Sarkar (1965), Sreenivasan (1973) and Shaha and Banerjee (1975) etc. used the technique of regression integral. This technique is presented briefly here. The technique takes into account only the total rainfall during a certain period and also its distribution over the period under consideration. It starts with linear form equation comprising the yield and meteorological factors.

$$Y = \alpha_0 + \alpha_1 r_1 + \alpha_2 r_2 + \dots\dots\dots\dots + \alpha_n r_n \quad \dots\dots (1.1)$$

Where Y stands for yield, r_1, $r_{2\ldots}$ r_n are the values of meteorological factor r in period n and the period represents equal sub-division of total period over which the impact of weather factor is to be studied. The partial regression coefficients a_1, $a_{2\ldots}$ a_n are the responses of r_1, $r_{2\ldots}$ r_n on yield. At the limit, the duration of each time interval is very small and the equation (2) becomes as:

$$Y = c + \int_0^T ar\, dt \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (1.2)$$

For each meteorological factor 'r', Meteorological Distribution Constants (MDCs) are estimated for each year by fitting an orthogonal polynomial of the 5[th] degree in tune to the values r_1, $r_{2,}$., $r_{n.}$

$$r = A_0 P_0 + A_1 P_1 + \dots\dots A_5 P_5 \quad \dots\dots\dots\dots\dots\dots (1.3)$$

Yield response to the MDCs (A_0, A_1…) assumed to take the following polynomial form.

$$a = B_0 P_0 + B_1 P_1 + \dots\dots B_5 P_5 \quad \dots\dots\dots\dots\dots\dots (1.4)$$

In order to estimate B_0, B_1…., yield is regressed on A_0, A_1 ….. such that

$$Y = B_0 A_0 + B_1 A_1 + \dots\dots . B_5 A_5 \quad \dots\dots\dots\dots\dots (1.5)$$

Sreenivasan (1973) study examined the relationship between the distribution of rainfall and cotton yields of Madhya Pradesh. Similarly, Shaha and Banerjee (1975) studied the effect of rainfall, humidity, maximum and minimum temperature each taken separately on cotton yields. From the result, it was found that minimum temperature was found to be crucial in explaining 75% of the total variation of yield.

(b) Studies Using Curvilinear Technique

The methodological up-gradation occurred again when Sreenivasan and Banerjee (1973) in another paper presented

[2] Although the temperature was taken care of by some studies like Kamalakar and Rao (1935), its inclusion was relatively confined to very few studies and entirely dependent on the availability.

the multiple regression technique taking the yield of Rabi Jowar in Raichur on mean maximum temperature, mean minimum temperature, total rainfall and total rainy-days. The multiple correlation coefficients were 0.54. However, the major breakthrough was brought in as the paper went on to experiment with the 'Multiple Curvilinear Regression' technique developed by Ezkiel and Fox (1965) on body of observation. The starting point is the linear regression of the standard type as:

$$Y = a_0 + a_1x_1 + a_2x_2 + \ldots\ldots\ldots a_nx_n \ldots\ldots\ldots\ldots \quad (2.1)$$

While this is useful first approximation, the relation between Y and each of the independent variables may have different and not necessarily linear form. The true relationship, in other words, would be of the following form:

$$Y = a_0^1 + a_1^1 f_1(x_1) + a_2^1 f_2(x_2) \ldots\ldots. + a_n^1 f_n(x_n) \ldots\ldots\ldots (2.2)$$

Where $f_1(x_1)$ ... etc. may have different forms, not necessarily linear. A process of successive approximation using freehand curves gets the nature and shape of it. The multiple and partial correlation coefficients are then estimated by feeding the freehand approximation of the curvilinear function into the equation (2).

(c) Construction of 'Weather Index'

In the mid-1960s when Indian studies were mainly confined with these two techniques, the Western scholars rejected the very idea of using the individual variable and developed one composite variable, i.e., 'Weather Index'. This was definitely an improvement over past methodologies. In this context, the theoretical study done by Shaw (1964) is noteworthy. He highlighted the difficulties involved in specifying the appropriate variables representing weather and functional relationship and problems of aggregation in multiple regression analysis[3]. He categorically specified the limitations with earlier methods of crop weather modeling. He pointed out that the monotonic inclusion of weather variable is not the approximation of reality. The monotonic inclusion of weather variable ignores the harmful effects. Again, one general functional form for different crops at different areas could not proxy the kind of relation that exists between the crop production and weather accurately. Finally, he suggested an alternative way to take care of all those misspecifications, i.e., weather index approach.

Bernard Oury (1965) discussed several methods of constructing weather index using aridity index[4]. It is too difficult to limit one when the problem of selection of variables comes to represent weather in the production model. Like Shaw (1964), he also mentioned that selecting single factor as the weather variable in an additive relationship runs the risk of assuming a wrong mathematical relationship. He also argued that the functional relationship between one of the weather factors with yield also depends upon the other factors. The concept of aridity index captures that interaction effect. So it is always lucrative to have one index made from several climatic factors in the crop production model. After incorporating the aridity index into the econometric model, he verified the performance of that index and compared with other models where the individual weather factors are modeled additively in a linear fashion. He was confirmed that when the climatic factors are merged gives better result than if they are modeled individually. Similarly Doll (1967) also constructed another weather index which more improved one, in which the meteorological factors are linked with weather index in a linear fashion but the weather index is a quadratic function of yield. The model displays diminishing marginal returns to weather in all time periods and diminishing total return to weather. Since meteorological effects in time periods are not assumed to be independent then the weather in each period interacts with weather in every other period. Thus, an index for year t can be computed as the ratio of the yield predicted for the actual weather that occurred during the year to the yield predicted had average weather occurred in the year. The base yield of the ratio changes with time when interaction is present. He also mentioned at the end the merits of using this method to construct weather index. This method of building weather index has been widely used now.

VI. Weather in Crop Forecasting

Another important use of weather is in the forecasting of crop production. Reliable pre-harvest forecasting is as important as the other production strategies such as quantity of inputs to be used, use of crop variety, cultivation technique etc. Forecasting is needed for government, traders, agro-based industries and agriculturalists alike (Chandrahas and Agrawal, 2006). Because forecast of crop production in advance of final estimates serves as an important aid for policy makers and administrators for taking decisions regarding the pricing policy, procurement, export and import etc. (Bhatia, 1997). The Directorate of Economics and Statistics in the Department of Agriculture and Cooperation, Ministry of Agriculture in India has been preparing the forecasting of crops for a quite large number of years. However, forecasting of crop production based on weather-crop model has of late drawn the attention of researchers and policy makers. In this connection, a brief survey of some studies on both methodological and empirical background has been given here. Indian Agricultural Statistical Research Institute (IASRI) also has done a well comprehensive review on pre-harvest crop production forecast methodologies (Op. Cit.). But here we have surveyed those studies which are based on weather variable.

One of the first studies that took place in India (Das and Vidhate, 1972) relates to Uttar Pradesh taken as a whole. This study is an attempt to forecast average yield of wheat per acre based on rainfall and temperature (maximum, minimum and mean) during the growing season from 1921 to 1966. All variables are averaged for the whole state and no distribution is made between irrigated and unirrigated areas. The increasing trend in yield observed since 1951 better assumed due to various development programmes are sought to be taken into account by introducing a suitable time scale linear variable in regression analysis. Arif (1988) tried to construct several behavioral functions that estimate the quantum of kharif food grain that is produced in India in relation to the

[3] This study is basically important in the sense that it pointed out so many loopholes and proposed the method index and also paved the way for further developments in that area.

[4] Oury (1965) discussed several aridity indexes and empirically verified two indexes and established the relative strength of aridity index than modeling the individual factors in a linear fashion.

spatial and temporal distribution of monsoon rainfall. Secondly, she also studied the predictability of kharif output based on progress of monsoon. Monthly rainfall data of 35 representative meteorological regions for the year 1979 to 1986 were taken. The monsoon rainfall index (MRI) was constructed by taking for both rice and food grains. For food grains, the volume of production relative to total food grains was taken as the weight and for rice the percentage area of rice of a particular region to the total cultivated area. For the crop weather model, she tried a number of alternatives.

Some studies like Parthasarathy et al. (1988, 1992) have tried to forecast food grain production on the basis of linear regression model from summer monsoon rainfall. They constructed both rainfall index and food grain production index. The influence of weather is separated from impact of technology on food grain production by fitting an exponential trend curve. All India monsoon rainfall is expressed as percentage of mean, denoted as MRI (monthly rainfall index) and rainy season food grain production as percentage of technological trend represented by an exponential curve fitted to the production time series, denoted as FPI (food grain index). The forecasting was done on the estimated model with regression coefficients. Similarly, the study by Bhatia (1997) forecasted kharif food grain and cereals. He used two models, i.e. (i) multivariate regression model and (ii) simple regression model in which index of weather influence was regressed against rainfall index. In both models, he used the trend variable as he mentioned that since it is hypothesized that production of various kharif food grain crops is influenced by many factors other than weather. Thus, he used the time trend to catch all variables and examined both in sample and out sample forecasting. The study by Aggrawal et al. (2001) used the same method of regression integral technique developed by Fisher (1924) with little modification for different agro-climatic zone basis.

VII. Weather in Supply Response analysis

Economic growth accompanied by rising population and income level leads to increase in demand for agricultural output. On the other hand, supply of output is governed by many factors like the price mechanism, weather, infrastructural facilities like irrigation, HYV seeds, fertilizers, pesticides etc. However, in a state of backward economy where the adoption and diffusion of technology is very slow or close to nil, weather along with price mechanism plays a vital role in shaping the supply of agricultural commodities. Again for ensuring the balance between demand for and supply of food grains, it is important task for planning authority and government in developing economy to study the supply analysis and the prominent factors influencing the supply of agricultural output. Here, we review some studies in this area that have taken 'weather' as one of the variables. In this connection, the pioneering work on supply response analysis started with work of Nerlove (1963). He used the 'Distributed Lag' model to study farmer's response to price. The basic equations are given as:

$$X_t^* = \alpha_0 + bP_{t-1} + cy_{t-1} + gZ_{t-1} + hW_t + u_t \quad \text{.......... (3.1)}$$

$$\text{And } (X_t - X_{t-1}) = B(X_t^* - X_{t-1}) \quad \text{.......................... (3.2)}$$

Where $\boldsymbol{X_t^*}$ is the standard irrigated acreage that would be planted by farmers, X_t is the standard irrigated acreage, P is relative price of crops, Y is relative yield of crops, Z is total irrigated area in all crops in season, W is rainfall and B is Nerlovian adjustment coefficient. After adjustment, the final equation is derived which is estimable one. But the point is that the weather variable is taken as linear fashion. Just after this study, numerous studies were initiated both in India and abroad following this Nerlovian tradition but none of the studies deviated from it so far as the treatment of weather variable is concerned. The studies in India like Raj Krishna (1963), Pathasarathy and John (1959), Satyanarayan (1967), Bapna (1980) and in abroad the studies like Behrman (1968) and others followed the same tradition. In fact, they did not pay much attention to the weather variable; simply it was taken as one of the control variables.

Lahiri and Roy (1985) work is one of the noteworthy studies. This study is particularly important because it has analyzed the weather factor, i.e., rainfall very systematically under the assumption that the impact of drought (scarcity of rainfall) is much more than the impact of flood (excess rainfall). So the response function is not like the monotonic one showing the increasing benefit of rainfall to the crops nor is it like the quadratic function reflecting the equality of impacts of both flood and drought. The response function is derived from the 'Gama Curve' analysis. He has carefully modeled the rainfall. However, most of the studies after this one are more or less similar in the sense that they took the weather variable in a monotonic fashion. The only point taken care of is the selection of weather factors on seasonal basis or month-wise (Pandey et al. 1997; Sharma and Joshi, 1995).

VIII. Trend Estimation, Yield, and Technology

Though the study of influence of weather on crop was initiated much before and passed through different stages of methodological improvement, the study of trend representing the technological progress or technology effect on yield was not a matter of much interest to the researchers before 1940s (Shaw, 1964). Earlier the yield was considered as a function of weather and some direct measurable inputs. However, later on it was realized that a substantial part of variation in yield has been due to technology. Thus, the researcher started incorporating the trend variable in the model because there is a need to remove the technology effect of yield variation before analyzing the impact of weather on crops and subsequently it also went through different stages of methodological development. Stalling (1960, 61) used a linear trend in his analysis showing that yield is a monotonic increasing function of technology. Some authors (like Morgan, 1961; Thompson, 1969 and 1971) also used the linear trend even after some authors sharply objected to it. In another paper, Lee et al (1969) based on the earlier realization of the fact yield is a function of weather, technology and inputs, used the deviation of trend yield from actual yield ($Y-Y_T = Y_W$) for weather analysis as it was assumed that it is a function of meteorological variables. However, in computing the trend yield he used linear regression. But, some authors started objecting the use of linear trend and Shaw (1964) was the first to raise voice against it. He categorically dejected the linear use of trend because it systematically underestimates first and then overestimates the yield effect of changing technology.

Figure 1 shows how linear trend does so. Suppose that there are two technological spurts which stimulate more crop production at two different time points. The first one is due to

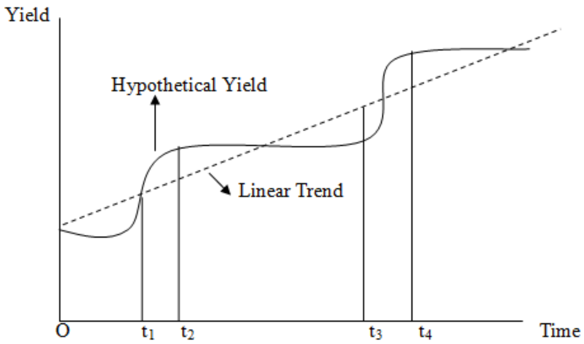

Fig.1: Linear and Hypothetical Trend of Yield

fertilizer that starts at time T_1, after which the hypothetical yield (representing actual yield) curve becomes steep upwardly showing the sudden rise in crop yield. After it reaches T_2, it becomes flat because every farmer adopts this technology. Again, at T_3 the HYV seeds technology comes and there is a rise in yield making the hypothetical yield curve steeper upwardly. However, the linear trend shows a constant rise of yield. Therefore, within the range OT_1, the trend yield is more than the actual yield and in the range $T_1 T_2$, the linear trend yield is less than actual yield. Same thing happens if we see the HYV seeds technology. Thus, it first underestimates and then over estimates the yield effect of technology variation.

Shaw (1964) also suggested one alternative method where he calculated nine years moving average from actual yields and taking those figures which fell within the 85 to 115 percent of moving average, estimated the trend using either a five-year moving average or linear regression. But, this is not free from black spots. Doll (1967) pointed number of loopholes in Shaw's method. First, the moving averages are also subject to Slutsky effect.[5] Again, he showed the technology as monotonically increasing function that increases in slope and becomes flat after complete adoption. Then, a moving average trend would fall on such a function only during periods of constant technology; a linear trend would fall on it at the point of intersection or tangency and since the weather index is estimated as the deviation from trend, it would make the index bias. Prof. Doll also suggested a different technique of crop weather model where he used a weather index. In his model, he used the polynomial of trend up to third degree, which could take care of the substantial increase in crop yields. He showed that inclusion of trend function in the model provides an improved estimate of meteorological response function and it holds well, regardless of the presence of weather trend interaction.

IX. Some Limitations of Previous Studies

The review in the present study shows the evolutionary stages that the crop weather modeling has gone through. There are some loopholes or research gaps in the literature that are to be taken care of in future studies. Here we discuss the limitation exist the past studies as follows. One of the important problems is in the wrong specification of models. Primarily the wrong specification of the response function of yield to weather parameters is responsible for causing loopholes in the crop-weather modeling. In most of the studies, generally the researchers take the weather variable as the monotonic function of yield or quadratic function. This depicts that yield is an increasing function of rainfall or temperature while the latter shows that the equality between the positive or negative effects of weather though it goes little far to point out some negative impacts on crops. In this regard, of course, the work by Lahiri and Roy (1985) in supply response analysis is an improvement, but the temperature is ignored in the equation since it is basically a supply response study. There may be other distribution like 'normal probability distribution' that may fit the rainfall pattern well. Again, most importantly the selection of period based on phonological development of crop is something that has been grossly ignored by the researchers. Though, Oury (1964) has suggested the aridity index should be taken at three different periods like (a) planting, (b) growing and (c) harvesting time. Nevertheless, most researchers take monthly weather variables on seasonal basis. Thus, there is a difference between meteorological time and phonological time as meteorological time is measured by the calendar while phonological time shows the growth stage of crops. Thus, both differ from each other.

Many researchers rejected the use of individual weather variables in the model on the ground that the response behavior between yield and weather parameters is not clear. They advocated the use of a composite index constructed from various weather variables[6] for analyzing weather impact as explained at length and breadth in papers by Stalling (1961), Oury (1964) and Doll (1967). However there are several limitations attached with the use of weather index. First, constructing 'weather index' by taking temperature and rainfall jointly together is the process of putting equal importance to both the factors but the behavioral relation between the precipitation and temperature with yield is not the same everywhere in the globe. Because different weather factors are important in different places so far as their variation and interaction with crop yields is concerned. For example temperature along with snowfall, wind velocity etc. does not pose any constraint on Indian agricultural sector. Again, the agriculture in the arid and semiarid areas like India the variation in temperature is not a crucial factor since it is minimal during a particular phonological period of crop growth. It varies within the day, reaches peak and comes down again. Other factors like snowfall, storm etc never comes as hindrance to the Indian agriculture. Thus, following the same procedure to analyze the crop weather relation is not justified. Here rainfall stands out as the single and most important factor influencing the agricultural practices, farmer's decisions making process and finally the yield and acreage behavior of Indian agriculture. Second, the difficulty involves in weather index is that if the response function between weather variables and yield is not clear then how

[5] If the variables representing cyclical pattern, is moving averages of past determining quantities that were not serially correlated, either real-world moving averages or artificially generated moving averages, then the variables of interest would become serially correlated, and this process would produce a periodicity. For details see Slutsky (1937).

[6] For limitations attached with different weather index is discussed by Doll (1967).

come the response function between yield and the weather index made of different variables takes a specific functional form. Doing this researchers commit the error that over a particular phonological period all the meteorological factors may not behave in the same manner meaning thereby that they are not conducive or harmful to the same extent. Thus using weather index made from the combination of these factors means assigning same weights to all the factors. However, the weather index suggested by Doll (1967) is different from others in the sense that it considers the meteorological factors separately and constructs the index. In that it was assumed that weather index is linearly related to meteorological factors of different sub-periods of particular phonological period of crop growth i.e. growing period but the functional behavior between yield and weather index is quadratic. But the same question comes here that the response function between yield and rainfall is not a bell-shaped normal curve. Thus there needs to be a response function between the yield and different weather parameters based on reasonable agronomic assumptions and decline the use of weather index. The logic behind it is that it is relatively easy to perceive the behavioral function between yield and weather parameters than the one between yield and weather index which is nothing but a series of numbers generated from a well mélange of different meteorological parameters.

Thirdly, the index methods discussed by Stalling (1961) and fine-tuned subsequently by Doll (1967) are based on experimental plot data approach which generated the data from controlled experiments on the plot. But in reality field level data vary from plot data since the very process of crop weather interaction is different from each other in both cases. On the field the crop is not controlled for direct and indirect effects of weather i.e., influence of weather through diseases, pests, insects etc. So the relationship between these two is different from that of experimental plot. Now when it comes to forecasting of crop output, there are also some lacunas that need to be taken out. But since forecasting also depends upon the response model, most of the loopholes discussed above also involves in forecasting. Thus taking care of response model ultimately leads to rectification of forecasting of crops. However, still there are some points that need to be addressed. While constructing the Monsoon rainfall index (MRI), the normal year or the average of some years should be used. The information regarding irrigation should be paid a heed in construction of MRI itself because it can mitigate much of the adverse effects. Agarwal et al. (2001) used the Fisher's regression integral technique for forecasting but that technique has its own defects on several grounds. First, it estimates the effects of each meteorological factor and its time distribution separately, but not in combination. This requires a more complicated model which will have yields on the one hand and the combination of other meteorological factors on another hand. But the simplest method is an additive model which postulates the separate effects of each meteorological variable, like those of the values of any particular factor in different parts of the growing season, are independent of each other. However, this is the most beleaguered way of getting things done. Even Minhas et al. (1974) believe that there is a strong reason to believe that the adverse effect of moisture stress at different stages of crop growth tend to be cumulative rather than additive. Secondly, this method is dependent on the data from confined experiments specifically designed to control for all influences on yield which raises another question about the rationality of its use. Thirdly, again taking a presumed response function does not render any flexibility to the model to capture the entire influence of a particular meteorological factor. Again, when it comes to taking out the impact of technological progress in production, the early studies starting from Thompson (1970) to till the most recent study of Tanura (2008) usually take a time trend as catch all effect factor. However, Shaw (1964) discusses the danger involved in it but the remedy suggested by him is not enough. The technological progress is represented by many factors like use of HYV seeds, fertilizer consumption, pesticides and mechanization of cultivation etc. and ultimately irrigation facility. But simply taking't' as trend variable leads to misspecification of the model. Therefore, these variables need to be incorporated in the model separately along with the time trend to catch the impact of other variables if any. The course of technological progress that takes place as depicted in the figure -1 resembles a logistic function and taking t never shows the reliable result. However Doll (1967) used a cubic function of time which, though is not a direct solution somehow improved the result. This study takes clue from that and incorporated it in the suggested model.

X. Summing up

Theoretically an ideal measure of weather impact would be that one which will satisfy some criteria like; first, very simple to construct and understand. Second, it should be based on the reasonable agronomic assumptions so that peculiar nature of agricultural sector of different regions would be taken care of effectively. Because the very nature of agricultural sector varies from one place to another, for example, if it is fully irrigated then rainfall beyond optimum is more dangerous than no rainfall or scanty rainfall. Similarly if it is completely dry land rain-fed agriculture then the less rainfall will have more repercussions than the more rainfall beyond optimum. This difference in character of agricultural sector leads to palpable difference in response function of rainfall to yield. Therefore, while modeling this point should be paid a heed to. Third, it should not be based on experimental plot level data so that the universality of the method can be established. Finally, it would be more convenient to incorporate the individual meteorological variables rather than have a composite index made of those variables. Because, it is relatively easy to perceive the response behavior between yield and weather parameters than the one between yield and weather index (made of those parameters) which renders nothing but a series of numbers free of units of measurement. Even Oury (1965) though advocated weather index, but the empirical verification did not render enough improvement to justify its use. Again incorporating the index in a particular way based on certain assumption also makes the problem more problematic since we really do not know about the response function between these two. Thus, by the process of doing it means ultimately we get ourselves entrapped in the same problem of not knowing the exact relation but assuming a possible response function that may be wrong approximation of the relation between them. The present paper reviewed the studies on the evolution of the weather-crop modeling, both in India and abroad. It does not claim to be complete one since only covers the studies done in/on India and some major studies abroad contributing to the methodological improvement. However so far as the number of papers covered here, it fairly represents a cross section of the works. Unfortunately the term 'weather' includes many factors which are sometimes not possible to capture. Thus, only rainfall and temperature are discussed mostly in the studies dealing with crop weather relation. But efforts are always initiated to make the things better for our understanding. Thus this study is a modest attempt to bring out that trend of getting crop-weather relation more and more fine-tuned. Again the determinants of weather are numerous and make the relation more complicated. They interact with non-weather factors and influence the crops indirectly. Thus, a completely perfect specification is quite difficult unless we acquire more scientific knowledge about the exact effects of both technology and meteorological factors on yield.

REFERENCE

1. Agrawal, Ranjan, Jain, R.C. and Mehta, S. C. 2001. Yield Forecast based on Weather Variables and Agricultural Input on Agroclimatic Zone Basis, Indian Journal of Agricultural Science, 71 (7): 487-490.
2. Arif, R.R. 1988. Kharif Production and Monsoon Rainfall: An Empirical Study, Reserve Bank of India Occasional Papers, 9 (4): 375-393.
3. Bapna, S. L. 1980. Aggregate Supply Response of Crops in a Developing Region, Sultan Chand and Sons Publications, New Delhi.
4. Barrios, Salvador, Luisito Bertinelli, and Strobl, E. 2010. Trends in Rainfall and Economic Growth in Africa: A Neglected Cause of the Growth Tragedy, Review of Economics and Statistics, 92(2): 350-366.
5. Behrman, J. R. 1968. Supply Response in Underdeveloped Agriculture: A case study of four Major Annual Crops in Thailand 1937-1963, North Holland, Amsterdam.
6. Bhatia, M.S. 1997. Rainfall Forecast and Kharif Production in 1997, Economic and Political Weekly, 32 (36): 2289-2294, September.
7. Bhattacharya, B. B. and Kar, S. 2006. Shocks and Long run Growth in Agriculture: A Macroeconomic Analysis" in R. Radhakrishanan et al. India in a globalizing world: Some issues of macro economy, agriculture and poverty (ed), Academic Foundation Press.
8. Biswas, B.C. and Maske, S. J. 1981. Rainfall Analysis for Use in Dry Land Agriculture', Indian Journal of Soil Conservations, 9 (2 & 3).
9. Black, J. R. and Thompson, S. 1978. Some Evidence on Crop-Weather-Yield Interaction, American Journal of Agricultural Economics, 6(3): 540-543.
10. Chandrahas and Agrawal, R. 2006. Pre-harvest Crop Production Forecast Methodologies: IASRI studies, Indian Agricultural Statistics and Research Institute, New Delhi.
    Available at www.iasri.res.in/Sovenior/Article_06.pdf).
11. Cummings, R. W., Jr. and Ray, S. K. 1969. 1968-69 Food-grain Production: Relative Contribution of Weather and New Technology, Economic and Political Weekly, September 27: A163-174.
12. Das, T. C. and Vidhate S. G. 1971. Forecasting Wheat Yield with the Help of Weather Parameters- part-III, Uttar Pradesh, IMD, Scientific Report No. 160.
13. Deshpande, R. S. 1980. Bibliography on Crop Weather Relationship, Indian Journal of Agricultural Economics, 35(2): 144-152.
14. Dixon, B.L., Steven E. Hollinger, P. Gracia and Tirupattur, V. 1994. Estimating Corn Yield Response Models to Predict Impact of Climate Change, Journal of Agricultural and Resource Economics, 19(1): 58-68.
15. Doll, J. P. 1967. An Analytical Technique for Estimating Weather Indexes from Meteorological Measurements, Journal of Farm Economics, 49(1): 79-88.
16. Ezekiel, M. and Fox, K. A. 1965. Method of correlation and regression analysis, John Wiley.
17. Fisher R.A. 1924. The Influence of Rainfall on the Yield of Wheat at Rothamsted, Philosophical Transactions of the Royal Society, B: 213: 89-142.
18. Gadgil, S. and Gadgil, S. 2006. The Indian Monsoon, GDP and Agriculture, Economic and Political Weekly, 41 (47): 4887- 4895.
19. Gangapadhyaya, M and Sarkar, R P. 1965. Influence of Rainfall Distribution on Yield of Wheat Crop, Agricultural Meteorology, 2(5): 331-350.
20. Gracia, Philip, Susan E. Offutt and Pinar, M. 1987. Corn Yield Behavior: Effects of Technological Advance and Weather Condition, Journal of Climate and Applied Meteorology, 26: 1092-1102.
21. Jacob, S. M. (Undated), Mem., Indian Meteorological Department, XXI (XIV): 131-146.
22. Kainth, G.S. (1996), Weather and Supply Behavior in Agriculture: An Econometric Approach, Regency Publications, New Delhi.
23. Kamalakar R. J. and Satakopan, V. 1940. The Influence of Rainfall Distribution on the Cotton Yields at Government Experimental Farms at Akola and Jalgaon, Indian Journal of Agricultural Science, 10(3): 23-35.
24. Kamalakar R. J., V. Satakopan and Gopal Rao, S. 1935. Supplements to the Report of the Agricultural Meteorology Section, August: 41-77.
25. Kaufmann, R. K. and Snell, E.S. 1997. A Biophysical Model of Corn Yield: Integrating Climate and Social Determinants, American Journal of Agricultural Economics, 79(1): 178-190.
26. Keylen, M.S. and Koroma, S. S. 1991. Trend and Weather Variables and Distribution of U.S. Corn Yields, Review of Agricultural Economics, 13(2): 249-258.
27. Lahiri, A.K. and Roy, P. 1985. Rainfall and Supply Response: A Study of Rice in India, Journal of Development Economics, 18 (2-3): 315-334 .
28. Lee, J. and Connaughton, M. J. 1969. Effects of Weather on Wheat Yields, Irish Journal of Agricultural Research, 8(3): 349-357.
29. Lobell, David B., Kimberly Nicholas Cahill and Christopher B. Field, 2007. Historical Effects of Temperature and Precipitation on California Crop Yields, Climatic Change, 81:187-203.
30. Mallik A. K 1960. Preliminary Studies on Crop Weather Relations, Indian Journal of Meteorology and Geophysics, 11(4): 23-26.
31. Mallik, A. K. 1958. Effect of Weather on Crop Growth and Yield at Government Experimental farm at Dharwar", Journal of Biological Science, 1(1): 56-68.
32. Minhas, B.S., Parikh, K. S. and Sreenivasan T.N. 1974. Toward the Structure of a Production Function for Wheat Yields with dated Input of Irrigation ratio, Water Resources Research, 10(3): 383-393.

33. Morgan, J.J. 1961. The Use of Weather Factors in Short run Forecast of Crop Yields, Journal of Farm Economics, 43(5):1172-1178.
34. Nadkarni, M.V. and Deshpande, R.S. 1982. Agricultural growth, Instability in Productivity and Rainfall: Case of Karnataka, Economic and Political Weekly, 17(52): A127-A134.
35. Nair, R. K. and Bose, P. 1945. Influence of Humidity and Temperature on the Yield of Cotton, Sankhyā: The Indian Journal of Statistics, 7(2): 213-216.
36. Narasimhan, M. and Ramdas, L. A. 1937. Agricultural Meteorology: Prediction of Minimum Temperature on Clear Days at Selected Stations in India, Indian Journal of Agricultural Science, 7(5).
37. Narayana, N.S.S. and Parikh, K. S. 1987. Estimation of Yield Functions of Major Cereals in India, Journal of Quantitative Economics, 3(2): 287-312.
38. Nerlove, M. 1958. The Dynamics of Supply: Estimation of Farmers' Response to Price, John Hopkins University Press, Baltimore, and M.D.
39. Offutt, S. E., Philip Garcia and Pinar, M. 1987. Technological advance, Weather and Crop Yield behavior, North Central Journal of Agricultural Economics, 9(1): 49-63.
40. Oury, B. 1965. Allowing for Weather in Crop Production Model Building, Journal of Farm Economics, 47(2): 270-283.
41. Pandey, U. K., K.S.Suhag and Manocha, V. 1984. An Estimate of Demand for and Supply of Cereals, Coarse-grains, Pulses and Oilseeds in Haryana, Indian Journal of Agricultural Economics, 39(1): 84-99.
42. Parthasarathy, B., A. A. Munot and Kothawale, D. R. 1988. Regression Model for Estimation of Foodgrain Production from Summer Monsoon Rainfall, Agricultural and Forest Meteorology, 42: 167-182.
43. Parthasarathy, B., K. Rupa Kumar & Munot, A. A. 1992. Forecasting of Rainy-season Food-grain Production based on Monsoon Rainfall, Indian Journal of Agricultural Science, 62: 1-8.
44. Raj Krishna. 1963. Farm Supply Response in India-Pakistan: A case study of Punjab Region, The Economic Journal, 73(291): 477- 487.
45. Ramdas, L. A. and Kalamkar, R. J. 1938. Statistical Investigations on Crop-Weather Relationships in India, Sankhya: The Indian Journal of Statistics, 3(3): 285-290.
46. Rao, A. 1936. Scientific Notes, Indian Meteorology Department, 7(71).
47. Rao, B. M. 1964. A Study of Effects of Some Weather Factors on the Yield of Wheat in Ludhiana district of Punjab, Indian Journal of Agricultural Economics, 28(1): 222-231.
48. Rao, V.M. 1970. Farm Production Function Studies: Treatment of Weather and Selection of Functional Form, Economic and Political Weekly, 5(15): 635-641.
49. Ray, S.K. 1981. Weather, Prices and Fluctuations in Agricultural Production, Indian Economic Review, 16(4): 250-277.
50. Satyanarayana, Y. 1967. Factors Affecting Acreage under Sugarcane in India, Indian Journal of Agricultural Economics, 22(2): 79-87.
51. Schlenker, W. and Roberts, M. J. 2006. Non-linear Effects of Weather on Corn Yields, Review of Agricultural Economics, 28(3): 391-398.
52. Shaha, S. K. and Banerjee, J. R. 1975. Influence of Rainfall Humidity and Sunshine, Maximum and Minimum Temperature on the Yield of Cotton at Coimbatore, Indian Journal of Meteorology Hydrology and Geophysics, 26(4): 518-524.
53. Sharma, V. P. and Joshi, P. K. 1995. Performance of Rice Production and Factor Affecting Acreage under Rice in Coastal Region of India, Indian Journal of Agricultural Economics, 50 (2): 153-166.
54. Shaw, L.H. 1964. The Effect of Weather on Agricultural Output: A Look at Methodology, Journal of Farm Economics, 46(1): 218-230.
55. Sivasami, K.S. 2000. Drought and Rainfall Pattern, 1877-1999, Economic and Political Weekly, 35 (24): 1993-94
56. Slutsky, E. 1937. The Summation of Random Causes as the Source of Cyclical Process, Econometrica, 5: 105-146
57. Sreenivasan, P. S. 1973. The influence of Rainfall on the Yield of Rainfed rice at Karjat. Agricultural Meteorology, (Amsterdam), 11: 285-292.
58. Sreenivasan, P.S. and Banerjee, J. R. 1972. Fisher's Regression integral versus Regression function of Selected Weather Factors in Crops Weather Analysis, Indian Journal of Meteorology and Geophysics, 23: 385-392.
59. Sreenivasan, P.S. and Banerjee, J. R. 1973. Studies on the Forecasting of Yield by Curvilinear Technique: Rabi Jowar at Raichur, Indian Journal of Meteorology and Geophysics, 24 (1): 49-55.
60. Stalling, James L. 1961. A Measure of Influence of Weather on Crop Production, Journal of Farm Economics, 43 (5):1153-1160.
61. Stallings, J. L. 1960. Weather Indexes, Journal of Farm Economics, 42 (1): 180-86
62. Swanson, E.R., F.A. Huff and S.A. Changnon, Jr. 1972. Potential Benefits of Weather Modification for Illinois Agriculture, Illinois Agricultural Economics, 12(1): 31-36.
63. Tannura, M.A., Scott H. Irwin and Good, D. L. 2008. Weather, Technology and Corn and Soybean Yields in the U.S. Corn Belt, Marketing and Outlook Research Report 2008-01, Department of Agricultural and Consumer Economics, University of Illinois at Urbana-Champaign.
64. Thompson, L. M. 1963. Evaluation of Weather Factors in the Production of Grain Sorghums, Agronomy Journal, 55: 182-185
65. Thompson, L. M. 1969. Weather and Technology in the Production of Corn in the U.S. Corn Belt, Agronomy Journal, 61: 453-456.
66. Thompson, L. M. 1970. Weather and Technology in the Production of Soybeans in the Central U.S., Agronomy Journal, 62: 232-236.
67. Thompson, L. M. 1986. Climatic Change, Weather Variability and Corn Production, Agronomy Journal, 78: 649-653.
68. Unakar, M. V. 1929. March rainfall of North-West India and Agra Upper Winds in December-January, IMD Mimeo, XXV (IV):131-146.
69. Vaidyanathan, A. 1980. Influence of Weather on Crop Yields: A Review of Agro-meteorologists Research, Working Paper no. 102, Center for Development Study, Trivandrum, Kerala.