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Statistical Modeling of Crop-Weather Relationship in India: A Survey on Evolutionary Trend of Methodologies

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ABSTRACT

Weather factors, like other inputs such as land, labor, seeds, irrigation, fertilizer, and pesticides are also direct inputs in crop production. In a state of agriculture where the adoption and diffusion of modern technologies is very low or almost nil, weather factors count more than other inputs because of their direct and indirect effects. Thus, the link between weather and crop yield will have implications on food supply and crop forecasting and management policies. It is of immense importance to the policymakers, agricultural scientists, agricultural economists, and meteorologists to understand this relationship. The methodology for studying this relationship has undergone many improvements over time. This paper attempts to review the studies in this area done in India and a few from abroad that brought an evolution in the methodology of crop-weather modeling.

Keywords: weather, crop yield, forecasting, modeling, supply response

JEL Classification: Q18, C51, C5

INTRODUCTION

The debate on the cause and effect relationship between weather and crop production has been an active area of research for different research communities, which include the agricultural scientists, meteorologists, and agricultural economists (Tannura, Irwin, and Good 2008). Agronomists and meteorologists tend to view weather as the dominant factor influencing the yield and acreage behavior of crops, while agricultural economists emphasize on the level of technology and other measurable inputs (Offutt, Garcia, and Pinar 1987).

The weather, like other inputs such as land, labor, seeds, fertilizers, and pesticides, among others, is also a direct input to agriculture. In a state of agriculture where the adoption and diffusion of modern technologies is very low or almost nil, weather factors count more than other inputs because of their direct and indirect effects. Weather factors such as rainfall and temperature produce different effects at various stages of crop growth. At some stages, these become conducive for growth while at other stages these are harmful. For instance, sufficient rainfall leads to more acreage at sowing period while it leads to more yield at growing stage. Similarly, temperature also has different impacts (Stallings 1960; 1961). The variation in production due to these uncontrollable exogenous factors sometimes outweighs the contribution of controlled variables leading towards an unstable crop production (Ray 1983).

In western economies, the study of weather crop relation in a systematic manner started a century ago. In India, however, it was initiated less than seven decades ago when the Indian Council of Agricultural Research (ICAR) launched the All India Co-ordinate Crop Weather Scheme (AICWS) in 1945 (Kainth 1996). The agricultural economy of India

with its rapidly growing population is closely linked with weather, in particular the monsoon. Under the scheme of AICWS, several meteorological observatories were set up throughout the country and systematic data on crop-weather relation for rice, wheat, and jowar were recorded. The Indian Meteorological Department (IMD) was the first to study this relation.

However, the systematic recording of data by meteorological departments on different climatic factors on the observatory plot with controlled experiment holds less relevance for the agricultural economy. This is because the weather is really uncontrollable as it affects crop production at various stages. One of the objectives of the studies on crop-weather relation by agricultural economists and agronomists is forecasting of crop production in advance. Both forecasting of weather by the meteorological department and the uncontrolled and real cause and effect relationship between weather and crop yield are needed in the forecasting of crop production. Thus, agricultural economists' study on crop-weather relations requires both controlled and uncontrolled data.

The economists' interest in the study of crop-weather relation is of relatively recent origin. There is a growing realization 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 other reasons for which the researchers need to have prior information about crop-weather relation.

First, the researcher should be in a position to describe and roughly classify the characteristics of the weather occurring from year to year in the study region so that the impact of weather on farm production can be delineated clearly. Secondly, some indications will be available to the researcher 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 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 ill effects of monsoons and ensure food security, food supply management, and overall growth of the economy.

Keeping the above-mentioned points in view, the present paper reviews some studies done both in India and abroad. Although the review does not claim to be comprehensive and extensive, it covers a good number of statistical studies conducted by economists, agricultural scientists, and meteorologists. This study also takes the help of two earlier surveys done by Ramdas and Kalamkar (1938) and Vaidyanathan (1980) in citing some of the past studies so as to maintain the continuity of the process of evolutionary trend of methodological development.

The specific objectives of this study are: (1) to bring out the evolutionary trend that the crop-weather modeling has gone through in evolving itself into a more fine-tuned and sophisticated area of research, which gradually makes it closer to reality, and (2) to point out some loopholes that still exist in recent studies.

NEED FOR THE SURVEY

The application of statistical methods to crop-weather analysis was 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 in this area of research.

Weather still plays a prominent role in agricultural production despite the use of modern technology since the 1960s in India. The meteorologists, agronomists, and agricultural economists, looking at different aspects of weather influencing directly or indirectly crop production, have put their efforts to make the analysis more fine-tuned and the results closer to reality. Ramdas and Kalamkar (1938) and Vaidyanathan (1980) surveyed the existing literature in this vital area of research in different contexts at different points in time. An important point of departure of the 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 the passage of time. The two surveys (by Ramdas and Kalamkar 1938, and Vaidyanathan 1980) of the studies in this area are narrower because these studies only reviewed the works done in India by citing only the results and the methodologies used. However, they did not depict the evolutionary trends in methodologies. The present study is different from them in the sense that while it mainly focuses on Indian studies, it also cites the major studies abroad, contributing to the sophistication of the methodology. Again, it intends to find out the limitations of all the existing methodologies and attempts to suggest a roadmap for future research.

ANALYTICAL STUDIES ON CROP-WEATHER RELATION

Meteorologists have initially experimented on diverse methods by taking weather as a variable for different purposes. Weather

includes precipitation, temperature, humidity, solar radiation, evapotranspiration, and so on. This section presents a review of studies initially undertaken in different weather stations. Various functional forms have been shown to make the analysis more explicit.

Simple Methods in Early Indian Studies¹

The early Indian studies during the 1930s employed simple methods of correlation, and linear regression was done later on. Ramdas and Kalamkar (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 (dates of publication have not been traced), Jacob used the correlation coefficient between acreage and rainfall in the Punjab region over a period of 19 years and 29 years in his first and second papers, respectively (in Ramdas and Kalamkar 1938, p. 285). Unakar (1929) also used the same methodology for wheat in Punjab.

After these three studies, the methodology was slightly fine-tuned and researchers started using linear regression model where weather parameters such as rainfall and temperature (W_{it}) were regressed on crop yields (Y_{it}) along with other variables comprising direct inputs (I_{it}) to agriculture. The basic model was designed as follows:

$$Y_{it} = \beta_0 + \beta_1 W_{it} + \beta_2 I_{it} + \epsilon_{it} \quad (1)$$

Using the same methodology, Kalamkar and Satakopan (1940) studied the effect of sowing season rainfall and the pre-sowing season price on cotton acreage for eight districts of Bombay presidency. They emphasized on weather and market because of the idea that weather conditions during sowing season affect

acreage as certain types of weather conditions may be considered suitable for a particular crop. Market price, on the other hand, has its reaction on acreage by influencing the mind of the cultivator as to the most profitable way of allotting the land to different crops. Many studies applied the same methodology, while studying the impact of weather, in particular, of rainfall (Kalamkar, Satakopan, and Rao 1935; Rao 1936; Narasimhan and Ramdas 1937).

Further Development in Methodology under AICWS

Utmost care and imagination evidently went into the design of crop weather observation. Large volume of information was collected in various meteorological stations for the period of five years to 20 years on different weather variables under the scheme of AICWS in India. This led to significant improvement in the methodology of crop-weather modeling in the country.

In the early 1960s and 1970s, various state branches of the Meteorological Department of India produced many papers on crop-weather relations that were distinct from the earlier Indian studies of the 1930s and 1940s with regard to the methodology used. For example, in the multiple regression model, weather parameters considered were rainfall, number of rainy days, temperature (both maximum and minimum, and mean of the two), sunshine, and humidity, etc.²

On the other hand, Mallik (1958) examined the nine-year data for three crops, namely, wheat, jowar, and cotton. He concluded that the wheat yields were very low due to rust attack, which was caused by the abnormally

1 Development of this section is drawn from Ramdas and Kalamkar (1938).

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

low number of hours of bright sunshine days during November. From this, he also went on to conclude that unseasonal rains and cloudy conditions created conducive atmosphere for severe rust attacks. In another paper, Mallik et al. (1960) used the same procedure and found the significant effects of different meteorological variables at different time periods.

Studies using Fisherian Regression Integral

Some studies attempted to use the regression integral technique developed by Fisher (1924)³ for analyzing crop-weather relation. Some early Indian studies like Kalamkar and Satakopan (1935) and Nair and Bose (1945) also applied this technique. But, after the scheme of AICWS came to existence, many studies started using this technique while taking advantage of the sophistication initiated in the collection of data. The studies of Acharya et al. (1960), Gangopadhyaya and Sarker (1965), Sreenivasan and Banerjee (1972), Sreenivasan (1973), and Shaha and Banerjee (1975) 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 equations comprising the yield and meteorological factors similar to equation (2):

$$Y = \alpha_0 + \alpha_1 r_1 + \alpha_2 r_2 + \dots + \alpha_n r_n \tag{2}$$

where Y stands for yield, r_1, r_2, \dots, 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, \dots, a_n are the responses of r_1, r_2, \dots, r_n on yield. At the limit, the duration of each time interval is very small and equation (2) becomes:

$$Y = c + \int_0^T ar dt \tag{3}$$

For each meteorological factor r , Meteorological Distribution Constants (MDCs) are estimated for each year by fitting an orthogonal polynomial of the 5th degree in tune to the values r_1, r_2, \dots, r_n .

$$r = A_0P_0 + A_1P_1 + \dots + A_5P_5 \tag{4}$$

Yield response to the MDCs (A_0, A_1, \dots) assumed to take the following polynomial form:

$$a = B_0P_0 + B_1P_1 + \dots + B_5P_5 \tag{5}$$

In order to estimate B_0, B_1, \dots , yield is regressed on A_0, A_1, \dots such that

$$Y = B_0A_0 + B_1A_1 + \dots + B_5A_5 \tag{6}$$

Sreenivasan (1973) examined the relationship between the distribution of rainfall and cotton yields of Madhya Pradesh. The comparison of result of this technique with the linear model showed that linear model is slightly better in terms of the coefficient of determination value (R^2). However, both the techniques are reported well when the actual and predicted values of yield are compared. Similarly, Shaha and Banerjee (1975) studied the effect of rainfall, humidity, and maximum and minimum temperature each taken separately on cotton yields. From the result, it was found out that minimum temperature was crucial in explaining 75 percent of the total variation of yield. This methodology was extensively used during the period 1947–1967.

3 Although this technique was developed by Fisher in 1924, it was first used in an Indian study in 1935 by Kalamkar and Satakopan (mentioned in Ramdas and Kalamkar 1938, p. 288).

Studies using Curvilinear Technique

The methodological up-gradation occurred again when Sreenivasan and Banerjee (1973) in another paper presented 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 Ezekiel and Fox (1965) on the body of observation. The starting point is the linear regression of the standard type as:

$$Y = a_0 + a_1x_1 + a_2x_2 + \dots \dots a_nx_n \tag{7}$$

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:

$$Y = a_0^1 + a_1^1f_1(x_1) + a_2^1f_2(x_2) \dots \dots + a_n^1f_n(x_n) \tag{8}$$

where $f_1(x_1) \dots$ etc., may have different forms, and may not necessarily be 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 equation (2).

Construction of weather index

In the mid-1960s when Indian studies were mainly confined within these two techniques, i.e., Fisherian regression and Curvilinear techniques, the western scholars rejected the very idea of using the individual variable and developed one composite variable, i.e., weather index. Weather index is a composite index developed by taking different weather factors

like rainfall, temperature, evapotranspiration, and so on, which was an improvement over previous 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.⁴ 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 represent the kind of relation that exists between crop production and weather accurately. Finally, he suggested an alternative way to address all of these misspecifications, particularly through the weather index approach.

Oury (1965) discussed several methods of constructing a weather index.⁵ It is too difficult to limit to one factor when the problem

4 This study is important in the sense that it pointed out many loopholes in existing methodologies and proposed the method of weather index. Moreover, it paved the way for further developments in that area.

5 Oury (1965) discussed several aridity indexes, empirically verified two indexes, and established the relative strength of aridity index than modeling the individual factors in a linear fashion. He discussed many types of aridity indexes like Lang's index ($I_L = \frac{P}{\frac{1}{12} \sum T > 0}$,

De Martonne's index ($I_M = \frac{\sum_{i=1}^n P_i \cdot 12}{n} / \frac{\sum_{i=1}^n T_i}{n} + 10$

and Angstrom index ($I_A = \frac{P}{1.07T}$, among others.

Paltasingh, Goyari, and Mishra (2012) also mentioned few other aridity indexes such as Hydrothermal Coefficients index ($HTC = \frac{\sum_{i=1}^n P}{0.1 \sum_{i=1}^n T}$ and another dryness

index suggested by Ped (1975) as $S_i = \frac{\Delta T}{\sigma_{\Delta T}} - \frac{\Delta P}{\sigma_{\Delta P}}$.

All these aridity indexes could be used to measure weather impact on crop yield. However, Paltasingh, Goyari, and Mishra (2012) revealed that out of all these indexes, Angstrom index performs better.

of selection of variables comes to represent weather in the production model. Like Shaw (1964), he also mentioned that selecting a single factor as the weather variable in an additive relationship runs the risk of assuming a wrong mathematical relationship. Therefore, it is always preferable to have one index made from several climatic factors in the crop production model. He constructed one index based on data on evapotranspiration, which ultimately depends on climate, soil moisture supply, plant cover and land management. In 2012, Paltasingh, Goyari, and Mishra empirically verified all the weather indexes developed by Oury (1965) and few others and found the Angstrom index performing better.

Doll (1967) constructed a model where the yield is a quadratic function of meteorological variables. This is defined as:

$$Y_t = \beta_0 + \beta_1 Z_t + \beta_2 Z_t^2 + \epsilon_t \quad (9)$$

where $Z_t = \sum Z_{jt}$ and $\beta_1 > 0$ and $\beta_2 < 0$. The model displays diminishing marginal returns to weather in all time periods and diminishing total return to weather in those periods, in which $\beta_j < 0$. Z_{jt} is a transformed meteorological variable is a linear function of meteorological variables (X_s) like rainfall in the period j of the year t and α_s are weight functions. It is written as:

$$z_{jt} = \alpha_1 x_{1t} + \alpha_2 x_{2t} + \dots + \alpha_n x_{nt} \quad (10)$$

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:

$$I_t = \frac{\beta_1 z_t + \beta_2 z_t^2}{\beta_1 \bar{z}_t + \beta_2 \bar{z}_t^2} \quad (11)$$

where \bar{z}_t and \bar{z}_t^2 are the mean values of the z_{tj} and z_{tj}^2 for the n year period. In his

empirical result, he has taken eight weeks starting from June 7 and then constructed the transformed weather variable. The weather index is constructed 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 that 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 a weather index. This method of building a weather index is being widely used now.

WEATHER AS EX-POST PRODUCTION PHENOMENON IN STUDIES

Farm production function is a useful device to comprehend the diagnostic and policy implications of the use of inputs including weather on farms. Here, weather is used in the analysis of ex-post production phenomenon to predict the impact of weather variability and climate change. However, the weather factor is modeled in two different ways: (1) linear regression model by using time series data, and (2) linear regression model by using panel data.

Linear Regression Model on Time Series Data

In the linear regression model on time series data, the weather factor is modeled in linear fashion by using time series data over the years. The model is linear in parameters but sometimes it may not be linear in variables as the squared terms of the weather factors are also incorporated in the model. Use of weather as a variable of ex-post production phenomenon in this fashion is seen in the studies of Rao (1964), Cummings and Ray (1969), Rao (1970), Nadkarni and Deshpande (1982), Offutt, Garcia, and Pinar (1987), Kaufmann

and Snell (1997), Chen, McCarl, and Schimmelpfennig (2004), Cabas, Weersink, and Olale (2010), and Paltasingh and Goyari (2013a), among others. However, in these studies, rainfall and sometimes temperature are included in increasing monotonic fashion to show how much variability in yield is accounted for by the variability in weather. In the first five studies, yield is taken as a function of rainfall and some other variables.

Rainfall alone is included as substitute for weather and modeled as a monotonic increasing function. Some studies used the rainfall index to represent weather to know the impact of weather on production. Ray (1971; 1977) constructed one rainfall index, which was subsequently used in the studies of Ray (1981; 1983) and Dev (1987). Basu and Majumdar (2004) and Mehta (2013) used a similar rainfall index (RI) at district level that is expressed as:⁶

$$RI = \frac{(R_t - \bar{R})}{\bar{R}} \cdot 100 \quad (12)$$

where R_t is observed rainfall at period t and \bar{R} is normal rainfall.

In another study, Paltasingh and Goyari (2013b) explained the variation in output because of weather variability (W_v). They constructed the weather variability index by taking the Angstrom aridity index in the following manner:

$$W_v = \left[\frac{W_t - \bar{W}}{\bar{W}} \right]^2 \quad (13)$$

where W_v is weather variability index and W is Angstrom aridity index expressed as $Wt = (R/1.07^T)_t$. The notation R and T are rainfall and temperature in period t , respectively. This method of constructing the weather

variability index differs from that of Basu and Majumdar (2004) and Mehta (2013) on two points.⁷ First, it has taken one composite weather index comprising rainfall and temperature and it is expressed as squared of the ratio of deviation of actual from normal weather index to the normal weather index. Secondly, it is constructed for different phenological periods of crop growth. However, all these studies, whether modeling weather factors directly or as a composite index of various weather factors, used time series data in regression model. Few other studies like Chen, McCarl, and Schimmelpfennig (2004), Cabas, Weersink, and Olale (2010), and Paltasingh and Goyari (2013a) used both rainfall and temperature and also their interaction in the framework of feasible generalized least square (FGLS) method, which is estimated in three stages and explains the mean yield as well as the yield variability as function of those climatic variables and others.

Cross Sectional Regression Model

Another methodology developed by Mendelsohn, Nordhaus, and Shaw (1994) to measure the impact of climate change on agricultural production is known as the Ricardian model. This method assumes that farmers maximize their profits by allocating land to different crops in a declining order of fertility and climate condition, while everything else remains constant. As Birthal et al. (2014) argued the difference in productivity or land value spawns from the difference in climate conditions. Therefore, the land value or net revenue from production per unit of land from a cross section of heterogeneous units pertaining to a particular time point is regressed on climatic

⁶ Basu and Majumdar (2004) used both actual rainfall (R_t) and the deviation from normal rainfall ($W_t = R_t - \bar{R}$) in various growth model specifications to show the effect of rainfall on crop yield.

⁷ This method of constructing the weather variability index follows the standard procedure followed by Boyce (1987) to construct the yield variability series and Hurt and Garcia (1982) and Brennan (1982) to measure price variability.

factors along with other non-climate factors (BIRTHAL et al. 2014). The climatic factors like rainfall and temperature are usually included in the model in monotonically linear fashion. However, sometimes their squared forms and interaction with other factors are included in the model. Many studies in India used this methodology (Sanghi, Mendelsohn, and Dinar 1998; Sanghi and Mendelsohn 2008; Kumar and Parikh 2001; Kumar 2009; Kumar 2011). The model is specified as follows:

$$R_{it} = X_{it}\beta + W_{it}\gamma + W_{it}^2\delta + IW\alpha_i + \varepsilon_{it} \quad (14)$$

where R_{it} is farm level net revenues, X is vector's non-weather farm inputs, W_{it} is vector of weather factors like rainfall and temperature, and IW_{it} is the vector of interaction terms between temperature and rainfall. The weather factors are modeled on the basis of monthly figures or seasonal figures based on phenological time period of crop growth.

Panel Regression Model

Similarly, the panel data (at district level or state level over the years) have been used to estimate the linear model, where the weather factors are modeled in linear fashion or nonlinear fashion by adding their squared terms along with their individual factors. This method of panel regression is used by many Indian studies such as Guiteras (2009), Gupta, Sen, and Srinivasan (2012), Auffhammer, Ramanathan, and Vincent (2012), Krishnamurthy (2012), BIRTHAL et al. (2014), Pattanayak and Kumar (2014), Padakandla (2016), among others. All of these studies used mostly the fixed effect panel regression. Pattanayak and Kumar (2014, p.5) argued that "this method of fixed effects estimators in panel data models rely on variations in weather across time within a spatial unit (e.g., states, districts, counties, etc.) to identify the influence of weather parameters on the outcome of interest (i.e., yield)."

Therefore, it removes the time-invariant unobserved factors specific to the spatial unit, which may confound the true crop-weather relationship, and overcomes the omitted variables bias problem (Pattanayak and Kumar 2014). The fixed effect model used in all these studies can be specified as:

$$\ln Y_{it} = X_{it}\beta + W_{it}\gamma + \alpha_i + \delta_t + \varphi_i t + \varepsilon_{it} \quad (15)$$

where the Y_{it} is crop yield in it h unit (district/state or any specific region) and in year t , X_{it} is a vector of non-weather farm inputs, and W_{it} is the vector of weather variables including temperature, rainfall, and solar radiation, evapotranspiration, humidity, dry days, and so on. α_i are the district fixed effects accounting for the time-invariant district specific unobserved factors; δ_t and $\varphi_i t$ are the time (year) fixed effects and the district specific annual (linear) time trend, respectively; ε_{it} is the idiosyncratic error term. All these studies also looked into the impact of climate change on crop yield by taking different crops or one specific crop.

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, and cultivation technique, among others. Forecasting is needed for government, traders, agro-based industries, and agriculturalists alike (Chandras and Agrawal 2006). This is because forecasting of crop production in advance of final estimates serves as an important aid for policymakers and administrators in making decisions regarding pricing policy, procurement, exports, and imports, among others (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 long time. However, forecasting of crop production based on a crop-weather model has of late drawn the attention of researchers and policymakers. In this connection, a brief survey of some studies on both methodological and empirical background is initiated in this section.⁸

The first studies on yield forecasting that took place in India was by Das (1970) and Das and Vidhate (1971). These two studies attempted to forecast average yield of rice and wheat per acre based on rainfall and temperature (maximum, minimum, and mean) for India and Uttar Pradesh. All variables were averaged for the whole state and no distinction was made between irrigated and rainfed areas.

After that study, many researches on pre-harvesting forecasting of crops have taken place at the Indian Agricultural Statistical Research Institute (IASRI). Most of these (Agrawal, Jain, and Singh 1980; Agrawal and Jain 1982; Agrawal, Jain, and Jha 1983; Agrawal, Jain, and Jha 1986; Mehta, Agrawal, and Singh 2000; Agrawal, Jain, and Mehta 2001) used the Fisherian regression integral technique discussed above or sometimes a modified version of this methodology. The above approach was used to forecast yield of rice and wheat at district level in different situations, particularly through (1) rainfed district having deficient rainfall (rice), (2) rainfed district having adequate rainfall (rice), and (3) irrigated district (wheat). Other studies used the discriminant function analysis by taking the time series weather variables of 25–30 years for forecasting the crop yield of mostly rice and wheat (Rai and Chandrahas 2000; Aditya 2008).

Arif (1988) tried to construct the behavioral functions that estimate the quantum of kharif food grain that is produced in India in relation to the spatial and temporal distribution of monsoon rainfall. Secondly, the predictability of kharif output based on the progress of a monsoon has also been studied. Monthly rainfall data of 35 representative meteorological regions for the year 1979 to 1986 were taken. The monsoon rainfall index (MRI) was constructed for both rice and food grains. For food grains, the volume of production relative to total food grains was taken as the weight; for rice, on the other hand, the percentage area of rice of a particular region to the total cultivated area was derived. For the crop weather model, a number of alternatives were tried. The first formulation represents a behavioral relationship of output Q with time t and the monsoon rainfall index R covering total precipitation during June through September as:

$$\ln Q = A + bt + c \ln R \quad (16)$$

In the second variant, four monthly rainfall indices R replaced the cumulative MRI to give the specification:

$$\ln Q = a + bt + \sum_{M:June}^{Sept} C_m \ln R^m \quad (17)$$

The assumption here is that the monthly pattern of rainfall has greater relevance than a single aggregate monsoon variable. The third specification model takes the ratio as variables:

$$\ln (Q_{t+1}/Q_t) = a + b \ln (R_{t+1}/R_t) \quad (18)$$

Following another approach, the response model was estimated in two stages, assuming that deviations from the trend line are weather induced.

$$\hat{Q}_t = \alpha \beta^t \quad (19)$$

$$\ln (Q_t - \hat{Q}_t) = a + b \ln R_t$$

⁸ Chandrahas and Agrawal (2006) did a comprehensive review of studies on pre-harvest crop production forecast at the Indian Agricultural Statistical Research Institute (IASRI), New Delhi.

Here, the residual term of the first equation becomes the dependent variable at the second stage. This one gave statistically adequate fit but did not perform as well compared to the other three alternatives. Even for getting the negative impact of unfavorable rainfall, one quadratic variable of rainfall was added then as:

$$\text{Ln}Q = b_0 + b_1t + b_2Z + b_3Z^2 \quad (20)$$

where $Z = \text{Ln } R$. She forecast crop output based on this equation for all 19 states and also determined the aggregate figure.

Some studies such as that of Parthasarathy, Munot, and Kothawale (1988) and Parthasarathy, Kumar, and Munot (1992) have tried to forecast food grain production on the basis of a linear regression model from summer monsoon rainfall. They constructed both rainfall index and food grain production index. The influence of weather is separated from the 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 precipitation index). The forecasting was done on the estimated model with regression coefficients.

Similarly, the study by Bhatia (1997) forecast kharif food grain and cereals. He used two models, i.e., (1) multivariate regression model, and (2) simple regression model in which index of weather influence was regressed against rainfall index. In both models, he used the trend variable to measure the influence of many factors other than weather and examined both in-sample and out-samples forecasting.

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 such as the price mechanism, weather, infrastructural facilities like irrigation, HYV seeds, fertilizers, pesticides, etc. Weather, along with price mechanism, plays a vital role in shaping the supply of agricultural commodities. Here, some supply response studies where weather was taken as one of the variables are reviewed.

The pioneering work on supply response analysis can be traced to Nerlove's (1958) work. He used the distributed lag model to study farmer's response to price. The basic equation is given as:

$$Y_t = \alpha_0 + bP_{t-1} + cY_{t-1} + gZ_{t-1} + hW_t + u_t \quad (21)$$

where $(Y_t - Y_{t-1}) = \delta(Y_t^* - Y_{t-1})$ and Y_t^* is expected yield at current period, Y_t is the actual yield, P is relative price of crops, Y_{t-1} is lagged yield of crops, Z is total irrigated area in all crops in season and some other factors, W is rainfall, and δ is Nerlovian adjustment coefficient. After adjustment, the final equation is derived, which is an estimable one. But, the point is that the weather variable is taken as linear fashion.

After this study, numerous studies were initiated both in India and abroad following this Nerlovian tradition but none of these deviated from it so far as the treatment of weather variable is concerned. The studies in India like Krishna (1963), Satyanarayana (1967), Bapna (1980), Krishna (1982), Narayana and Parikh (1987), Mungekar (1997), Kanwar (2004), Mythili (2008)⁹ and others followed the same tradition.

9 Mythili (2008) used rainfall deviation from normal rainfall instead of taking rainfall directly.

In fact, they did not pay much attention to the weather variable; it was taken as one of the control variables.

Lahiri and Roy's (1985) work is one of the noteworthy studies in this area. 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 resembles the Gamma curve and expressed as follows:

$$Y = k.e^{-cR} R^d ; c, d > 0 \quad (22)$$

After taking logarithm of both sides, the final equation to be estimated is expressed as follows:

$$\text{Log } Y = K - cR + d \log R \quad (23)$$

where R is rainfall, c and d are unknown parameters to be estimated, and K is the constant.

The response curve is like the Gamma curve showing the fact that the impacts of droughts are more than that of floods. However, all researchers except Kainth (1996) repeated the same way of modeling the weather variable (mostly rainfall) in a monotonic fashion, even after this development in modeling the rainfall in supply response analysis. The only point considered is the selection of weather factors on seasonal or month-wise basis (Pandey, Suhag, and Manocha 1984; Sharma and Joshi 1995). Palanivel (1995) and Misra (1998) used a rainfall index developed by Ray (1977). However, Paltasingh and Goyari (2013c) used the Angstrom weather index as a substitute for the weather variable and found very significant influence on crop yield as well as acreage.

SOME LIMITATIONS OF PREVIOUS STUDIES

The review in the present study shows the evolutionary stages that crop weather modeling has gone through. There are still some limitations in the existing literature that need to be addressed in future studies.

One of the important problems is the wrong specification of models. In most of the studies, the researchers have generally taken the weather variable as the monotonic or quadratic function of yield. 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 quadratic function does not significantly point out the negative impacts on crops. In this regard, 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 a supply response study. The selection of period based on phenological development of crops is something that has been ignored by researchers although Oury (1965) suggested that the aridity index should be taken at three different periods: (1) planting, (2) growing, and (3) harvesting time. Nevertheless, most researchers take monthly weather variables on seasonal basis. Thus, there is a difference between meteorological time and phenological time as meteorological time is measured by the calendar, while phenological time shows the growth stage of crops.

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.¹⁰ They advocated the use of a composite index

¹⁰ For example, solar radiation, which is negatively correlated with rainfall, usually has a positive impact on photosynthesis, hence plant productivity. Hence, rainfall, normally expected to be positively related to yield, may also reflect the negative solar radiation effect, and the net effect is not clear.

constructed from various weather variables¹¹ for analyzing weather impact as explained in papers by Stallings (1961), Oury (1965), and Doll (1967). However, there are several limitations attached with the use of weather index.

First, constructing a weather index by taking temperature and rainfall jointly puts equal importance to both factors but the behavioral relation between precipitation and temperature with yield is not the same everywhere in the globe. 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., poses relatively less constraint on Indian agricultural sector in comparison to rainfall. The variation in temperature may not be a crucial factor in agriculture in the arid and semiarid regions like India since it is minimal during a particular phenological period of crop growth. It varies within the day, reaches peak, and comes down again. Other factors like snowfall, storms, and so on never come as hindrance to 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 decision-making process, and finally the yield and acreage behavior of Indian agriculture.

Second, if the response function between weather variables and yield is not clear, then the response function between yield and the weather index made of different climatic variables should not take a monotonic increasing functional form. In doing this, researchers commit the error of assuming that over a particular phenological period, all the

meteorological factors may behave in the same manner, thereby making these unproductive or harmful to the same extent. Thus, using the weather index as a monotonic function in the yield model intrinsically assumes the same functional form for individual factors that the weather index is made from.

Thirdly, the index methods discussed by Stallings (1961) and Doll (1967) are based on the experimental plot data approach, which generated the data from controlled experiments on the plot. In reality, however, field level data vary from experimental 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 an experimental plot.

There are also some lacunas that need to be taken out when it comes to forecasting of crop output. Since forecasting also depends upon the response model, most of the loopholes discussed above are also involved in forecasting. Thus, looking into the response model ultimately leads to rectification of forecasting of crops but there are still some points that need to be addressed.

While constructing the Monsoon Rainfall Index (MRI), the information regarding irrigation should be considered carefully because it can mitigate much of the adverse effects of scanty rainfall. Agrawal, Jain, and Mehta (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.

The simplest method is an additive model,

11 Limitations attached to different weather indexes is discussed by Doll (1967).

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 modeling the impact of weather on crop yield. Even Minhas, Parikh, and Srinivasan (1974) argued that there is a strong reason to believe that the adverse effect of moisture stress at different stages of crop growth tends to be cumulative rather than additive. Secondly, this method is dependent on the data from confined experiments, specifically designed to control all influences on yield, which raises another question about the rationality of its use. Thirdly, taking a presumed response function does not render any flexibility to the model to capture the entire influence of a particular meteorological factor.

CONCLUSION

In this paper, studies were surveyed on the basis of an evolutionary trend in methodologies to measure the weather impact on crop, both in India and abroad. It does not claim to be a complete survey since the major focus is on studies done in India and some major studies abroad contributing to methodological improvement. However, as far as the number of works surveyed here is concerned, it fairly represents a cross section of the studies.

Unfortunately, weather includes many factors, which are sometimes not possible to capture. Only rainfall and temperature were discussed in those studies dealing with crop-weather relation but efforts are always put for a better understanding of this relation. Therefore, this study is a modest attempt to bring out that trend of getting crop-weather relation more and more fine-tuned. The measures for weather variable are numerous, which makes the relation more

complicated. They interact with non-weather factors and influence the crops indirectly. Therefore, a completely perfect model specification is difficult to attain unless more scientific knowledge about the exact effects of meteorological factors on crop yield are acquired.

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