# Development of Rice Yield Forecast in Mid-season Using Weather Indices based Agrometeorological Model in Chhattisgarh

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***ABSTRACT***

*Eastern India accounts for more than half of the rice crop area in the country where rainfed rice is predominant. Rice is main food crop of Monsoon season in Chhattisgarh. Production of rice is mainly dependant on monsoon rainfall and weather prevailing in the season. Forecasting of yield of rice is useful for planning of food storage, export and pricing in the country. It is established that rice yield is correlated with prevailing weather in the season. Modified Hendricks and Scholl model which consider weather from sowing to week prior to forecast week is employed to develop regression model in different districts. The models used to forecast district level yield of rice in Chhattisgarh in mid-season of 2014 and 2015. Forecast yield obtained is validated with actual yield of corresponding year to find the accuracy of developed model. Forecast accuracy is less than 10% in 6 districts in 2014 and 4 districts in 2015.*

***Keywords:*** *Rice yield, Weather indices and Statistical regression model .*

## 1. Introduction

States in eastern India (Assam, Bihar, Orissa, West Bengal, Madhya Pradesh, Chhattisgarh and Uttar Pradesh) account for about 63.3% of the total rice cropped area in the country (26.8 million ha out of 42.3 million ha total). About 80% of the rice area of eastern India is rainfed and exposed to abiotic stresses such as drought, low soil fertility, flood and stagnant water(Singh and Singh, 2000). Rice cultivation in prevalent in all the 27 districts of Chhattisgarh in three agro-climatic zones namely Northern hill zone, Chhattisgarh plain zone and Bastar plateau zone. In Chhattisgarh, rice is grown in area of 3.6 million ha. with the productivity of the state ranging between 1.2 to 1.6 t/ha depending upon the rainfall. In view of topography, 20-30% of the rice is grown in low lying areas (Kanhar soil). Normally much irrigations are not required in this soil and one or two irrigations are sufficient to harvest a satisfactory production during normal rainfall year. The upland areas where rice is grown, constitute about 15-20% of the total cultivated area. The biasi (beushening) system of rice cultivation is most widely practiced in the state, where optimum plant population is major constraints for achieving higher productivity.

Pre-harvest forecasting of crop production facilitates decision and policy making of food stock, price fixation, distribution and import of food crops to enable food security of the country (Jayakumar and Rajavel, 2017). Ministry of Agriculture sponsored a scheme “Forecasting Agricultural output using Space, Agrometeorology and Land based observations (FASAL)” in State Agricultural Universities and India Meteorological Department to develop in-season multiple stage crop yield forecasts in food, oilseeds, and sugarcane, potato and fibre crops. Rice yield forecasts at district level for the state of Chhattisgarh is prepared jointly by Agrometeorological Field Unit in Indira Gandhi Krishi Viswavidyalaya, Raipur and Meteorological Centre, Raipur.

Fisher (1924) and Hendricks and Scholl (1943) have done pioneering work in crop weather relationship. Fisher’ assumption is that effects of change in weather variables in successive periods of time would not be abrupt, but an orderly one that follows some mathematical law. He modelled these effects as terms of a polynomial function of time.

Hendricks and Scholl (1943) have modified the Fisher's method with assumption that a second-degree polynomial in a week number was sufficiently flexible to express the effects in successive weeks.

Hendricks and Scholl (1943) and Runge(1968) have used this model to study joint effects of temperature and rainfall on crop yields. Baier (1977) made significant contributions in this field using empirical statistical models. In the empirical statistical model approach, one or several weather variables or a time trend are related with yield. Usually the independent variables such as rainfall, maximum temperature, minimum temperature, moisture, humidity etc. are related to yield. The weighting coefficients are obtained by using the multivariate regression analysis. Validity of such empirical models depends on the design of the model as well as on the representativeness of the input data. Such valid models are used for predicting purposes as well. Several empirical statistical models were developed all over the world. William et al. (1975) (Canada) developed models using weather variables and trend. In USSR, multi-variable regression equations were developed using simple or quadratic expressions of agro-meteorological variables and biometrical characters.

The Joint Agricultural Weather Facility (JAWF), a world agricultural weather information centre was established in 1978 by US Department of Agriculture (USDA). JAWF employs crop weather analysis models using weather data and derived agrometeorological variables to estimate crop yield. Statistical regression models are used to evaluate weighting coefficients, which evaluates the effects of weather on crop yield. Frere and Popove (1979) used the method designed by Crop Ecology and Genetic Resources unit of FAO in which actual rainfall data and climatological information are used.

Crop–weather models employing mathematical or statistical techniques provide a simplified representation of the complex relationships between weather/climate and crop growth, yield and yield components (Baier, 1979). Least-square regression is one of the principle methods of quantitative research to study crop–weather relationships (Jones, 1982). In this method, general approach is to regress a time series of the dependent variable (yield) with independent variables(meteorological variables).

Agrawal et al. (1980, 1983, 1986) and Jain et al. (1980) have developed forecast models for crops based on weather parameters. They modified the model suggested by Hendricks and Scholl expressing effects of changes in weather variables on yield in the $w^{th}$ -week as second degree polynomial in respective correlation coefficients between yield and weather variables. This will explain the relationship in a better way as it gives appropriate weightage to different periods.

Agrometeorological models or weather based statistical regression models utilise weather variables and crop yield to understand the variation in yield and correlation between yield and weather. The relationship between crop yield and weather parameters can be identified with the help of multiple regression models (Agrawal et al., 2001). Location specific models have been developed in India for food crops viz., rice, ragi and wheat( Tripathy et al., 2012; Singh et al., 2014; Kumar et al., 2014; Agnihotri and Sridhara, 2014: Rajegowda et al., 2014). Development of agrometeorological model with good accuracy for operational forecasting of rice at district level in Chhattisgarh has been presented in this paper.

## 2. Data and Methodology

### 2.1 Monsoon during 2014 and 2015

During 2014, South West Monsoon set in Chhattisgarh on 19th June and covered entire State on 19th June. State has received 1104.3mm of rainfall of during the South West Monsoon season. During the season, out of 18 districts, one district received excess rainfall, 15 districts received normal rainfall and two districts received deficient rainfall. In 2015, South West Monsoon set in Chhattisgarh on 13th June and covered entire Chhattisgarh by 23rd June. Quantum of seasonal rainfall received was 984.7mm during South West Monsoon season in 2015. One district received excess rainfall, 9 districts received normal rainfall and 8 districts received deficient rainfall.

### 2.2 Weather and crop data

Long term daily weather data for districts Surguja, Bilaspur, Raipur and Bastar are collected from respective district's meteorological observatory located in district headquarters and archived at National Data Centre, India Meteorological Department. Crop yield data is obtained from Directorate of Economics and Statistics and Department of Agriculture, Government of Chhattisgarh. Daily weather data is converted to weekly data for correlation and regression study. Crop and weather data ranging from 15 to 32 years in different districts have been utilised in the study. Before proceeding to correlation and regression analysis, detrending of yield was done to find out the influence of technological trend on crop yield over years.

**Table 1. Weather indices**

| Weather parameter | Simple weather indices | | | | | |
|---|---|---|---|---|---|---|
| | Maximum temperature (Tmax) | Minimum temperature (Tmin) | Rainfall (RF) | Relative Humidity (RH I) | Relative Humidity (RH II) | Bright sunshine hours |
| Maximum temperature (Tmax) | z10 | z120 | z130 | z140 | z150 | z160 |
| Minimum temperature(Tmin) | | z20 | z230 | z240 | z250 | z260 |
| Rainfall(RF) | | | z30 | z340 | z350 | z360 |
| Relative Humidity(RH I) | | | | z40 | z450 | z460 |
| Relative Humidity(RH II) | | | | | z50 | z560 |
| Bright sunshine hours | | | | | | z60 |
| | Weighted weather indices | | | | | |
| Maximum temperature (Tmax) | z11 | z121 | z131 | z141 | z151 | z161 |
| Minimum temperature(Tmin) | | z21 | z231 | z241 | z251 | z261 |
| Rainfall(RF) | | | z31 | z341 | z351 | z361 |
| Relative Humidity(RH I) | | | | z41 | z451 | z461 |
| Relative Humidity(RH II) | | | | | z51 | z561 |
| Bright sunshine hours | | | | | | z61 |

*Simple weather indice is sum of weather parameter

**Weighted weather indice is sum product of weather parameter and weight factor

### 2.3 Crop weather model

Hendricks and Scholl expressed crop yield in the following form, Where, $X_w$ denotes value of weather variable

$$Y = A_0 + a_0 \sum_{w=1}^{n} X_w + a_1 \sum_{w=1}^{n} {}_w X_w + a_2 \sum_{w=1}^{n} {}_{w^2} X_w + e$$

under study in $w^{th}$ week, n is the number of weeks in the crop season, $A_o$, $a_o$, $a_l$ and $a_2$ are the model parameters and Y is yield. This model was extended to study combined effects of weather variables and an additional variate T representing the year for time trend.

Hendricks and Scholl model has been modified in Indian Agricultural Statistical Research Institute where the effects of changes in weather variables on yield in the $w^{th}$ week were expressed as second degree polynomial in respective correlation coefficients between yield and weather variables (Agrawal et al., 1980, 1983; Jain et al., 1980; Agrawal and Jain, 1982). The relationship was, thus, explained in a better way as weather in different weeks receives appropriate weightage. Agrawal et al. (1986) further modified this model considering that the impact exerted by changes in weather variables in $w^{th}$ week on yield is a linear function of respective correlation coefficients between yield and weather variables. The significant effect of trend on yield was also removed while calculating correlation coefficients of yield with weather variables to be used as weights. The studies on effects of second degree terms of weather variables showed that (i) the models using correlation coefficients based on yield adjusted for trend effect were better than the ones using simple correlations and (ii) inclusion of quadratic terms of weather variables and also the second power of correlation coefficients did not improve the model. Full crop season data considering different weather variables simultaneously have been used to develop the

**Table 2. Regression equation developed for crop yield forecasting in 2014**

| SN | District | Equation | Weather Parameters in the equation |
|---|---|---|---|
| 1 | Koriya | $Y=-4593.697 + (0.861*z_{151})+(0.390*z_{361})$ | Maximum temperature, RH II, Rainfall, Sunshine hours(SSH) |
| 2 | Janjgir-Champa | $Y=-9239.246+(135.206*time)+(123.163*z_{41})+ (-14.509*z_{40})$ | Time, RH I |
| 3 | Raigarh | $Y=-1671.565+(0.528*z_{151})+(15.479*time)$ | Maximum temperature, RH II |
| 4 | Kawardha | $Y=-820.7918+(1.1380*z_{361})$ | Rainfall, SSH |
| 5 | Dhamtari | $Y = -6047.8 + (122.8132*time)+ (0.8821*z_{151}) +(0.739*z_{361})+(-0.2394*z_{560})+ (-0.12854*z_{360}) + (16.55*z_{20})$ | Time, Maximum temperature, Minimum temperature, Rainfall, RH II |
| 6 | Bastar | $Y = -2472.813 + (24.097 *time) + (0.143*z_{231}) + (478.960*z_{21} + 0.04718*z_{451})$ | Time, Minimum temperature, Rainfall, RH I, RH II |

forecast model in following finally recommended form.

$$Y = A_0 + \sum_{i=1}^{p} \sum_{j=0}^{1} a_{ij} Z_{ij} + \sum_{i=i'-1}^{p} \sum_{j=0}^{1} a_{ii'j} + cT + e$$

where,

$$Z_{ij} = \sum_{w=1}^{m} r_{iw}^{j} X_{iw} \quad \text{and} \quad Z_{ii'j} = \sum_{w=1}^{m} r_{ii'w}^{j} X_{iw} X_{ii'w}$$

where, $X_{iw}$/ $X_{ii'w}$ is the value of $i^{th}$/$i'^{th}$ weather variable under study in $w^{th}$ week, $r_{iw}$/$r_{ii'w}$ is correlation coefficient of yield (adjusted for trend effect, if present) with $i^{th}$ weather variable/ product of $i^{th}$ and $i'^{th}$ weather variables in $w^{th}$ week, m is week of forecast and p is number of weather variables used. Two weather indices were developed for each weather variable, i.e. simple as well as weighted accumulation of weekly weather variable, weights being correlation coefficients of weather variable in respective weeks with yield (adjusted for trend effect, if present). Similarly, indices were also generated for interaction of weekly variables, using weekly products of climate variables taking two at a time. Combination of weather variables for weather indices, thus, generated are presented in Table 1.

Weather variables used for this model are maximum temperature (Tmax), minimum temperature (Tmin), rainfall (RF), relative humidity and hours of bright sunshine from 28 to $38^{th}$ standard week for mid-season forecast($F_2$). Stepwise regression technique was used to select the important weather indices. The long term yield data excluding latest two years was used in developing the forecast model and the latest two years data was used for the validation of the model.

**Table 3. Regression equation developed for crop yield forecasting in 2015**

| SN | District | Equation | Weather Parameters in the equation |
|---|---|---|---|
| 1 | Bilaspur | Y= -5642.47+(0.101*$z_{231}$)+(0.041*$z_{450}$)+(0.86*$z_{141}$) | Minimum temperature, Rainfall, RH-I,RH-II |
| 2 | Durg | Y= 351.38+(18.59*time)+( 0.15* $z_{340}$)+ (-13.81 *$z_{30}$) | Time, Rainfall, RH-I |
| 3 | Kawardha | Y=542.43+(0.29* $z_{360}$) | Rainfall, RH-II |
| 4 | Kanker | Y = -755.59+(0.29*$z_{360}$)+ (-3.66*$z_{251}$)+(0.31*$z_{351}$)+(-0.89 *$z_{231}$) | Minimum temperature, Rainfall, RH-II |

## 3. Results and Discussion

### 3.1 Technological trend

Detrending analysis of yield of rice indicated that there is technological trend existed in some districts like Janjgir-Champa, Jashpur, Raigarh and Surguja. Adjusted yield is correlated with weather indices to quantify the absolute influence weather where there is technological trend.

### 3.2 Statistical model

The multiple regression equations which describe the average relationship between the yield of rice and significant weather parameters is derived and expressed in Table 2 and 3.

Rainfall, temperature, relative humidity and sunshine hours are the main weather parameters affecting the yield of rice in two years of study. Rainfall (spatial and temporal variation) is the direct critical weather parameter in rainfed ecologies. If water is not the limiting factor, the most important weather parameters are temperature and solar radiation. When considering the growth stages of rice, reproductive and ripening stages are the most sensitive stages to weather. Pandey et al. (2015) found that sun shine and rainfall is playing an important role in production of rice crop in Faizabad, Uttar Pradesh. Biswas et al. (2015) reported that minimum temperature, wind speed, relative humidity and two categories of date of transplanting (dummy variables) can predict the variation of 74% of rice yield in West Bengal.

Models developed could predict the rice yield in six districts namely Koriya, Janjgir-Champa, Raigarh, Kawardha, Dhamtari and Bastar in 2014 and four districts namely Durg, Kawardha, Kanker and Bilaspur in 2015 with error within ±10%(Table 4 and 5).

**Table 4. Forecast yield and error in 2014**

| District | Forecast yield(kg/ha) | Actual yield(kg/ha) | Error(%) |
|---|---|---|---|
| Surguja | 925 | 1995 | -54 |
| Jashpur | 2161 | 1779 | 21 |
| Koriya | 1815 | 1865 | -3 |
| Bilaspur | 1331 | 1772 | -25 |
| Korba | 1378 | 1655 | -17 |
| Janjgir- Champa | 3518 | 3319 | 6 |
| Raigarh | 1415 | 1478 | -4 |
| Raipur | 1326 | 1954 | -32 |
| Durg | 1819 | 2248 | -19 |
| Rajnandgaon | 1224 | 1757 | -30 |
| Kawardha | 1389 | 1357 | 2 |
| Mahasamund | 1215 | 1971 | -38 |
| Dhamtari | 2720 | 2576 | 6 |
| Kanker | 1740 | 1954 | -11 |
| Bastar | 1756 | 1954 | -10 |
| Dantewada | 1483 | 2248 | -34 |

During 2015, spatial and temporal distribution of rainfall in the season was not so good as in 2014 and due to this good prediction in less number of districts. Error per cent range from -10 to 6 % in 2014 and -4 to 8 % in 2015 in the above districts. In rest of the districts error was more than 10%. Further, excluding data of extreme years for model development may also be explored in further studies for achieving high accuracy in prediction. Ghosh et al.(2014) and Singh et al.(2014) found that error was less than 10% for most of major rice growing districts of West Bengal and East Uttar Pradesh in a similar study.

## 4. Conclusions

The following conclusions are drawn from the study:

(i) Rainfall, temperature, relative humidity and sunshine hours are the main weather parameters affecting the yield of rice in Chhattisgarh.

(ii) Statistical regression equations developed for district level yield forecasting of rice could predict rice yield within acceptable limits of error in six districts namely Koriya, Janjgir-Champa, Raigarh, Kawardha, Dhamtari and Bastar during 2014 and four districts namely Durg, Kawardha, Kanker and Bilaspur during 2015.

(iii) Model development with more years of data(20 years or more) may improve the prediction in many districts. Appropriate inclusion of Vegetation Condition Index (VCI), pest damage and derived indices may improve the prediction.

(iv) Improvement in accuracy of models by excluding data of extreme years for model development may be explored in further studies.

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