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Studies on the forecasting of yield by curvilinear technique: Rabi Jowar (Sorghum) at Raichur

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ABSTRACT. Systematic crop and weather observations twice-a-day (0700 and 1400 hrs local time) on rabi jowar at Raichur Agro Met. Observatory during 1948-67 have been analysed. The varieties under observations were M 35-1 and PJ-4R and each of 18 weeks in duration. Following Gangopadhyaya and Sarker (1963), the analysis of these observations were made to evaluate the curvilinear response of the crop. The present study has confirmed the advantage of applying curvilinear multiple correlation as to the behaviour of the crop in relation to weather as postulated by Gangopadhyaya and Sarker.

1. Introduction

Systematic crop and weather observations on rabi jowar at Raichur were started in 1948-49. The technique of recording observations is given in the *ICAR Monograph* on crop and weather in India (Ramdas 1960). The varieties under observation are M 35-1 and PJ-4R and both these varieties are of 18 weeks in duration. Weather observations have been recorded during this period in the agromet observatory twice a day, namely, at 0700 hr and 1400 hr local mean time. An analysis of these observations has been made to evaluate the curvilinear response of the crop.

2. Method of analysis

The method followed is the same as the one described by Gangopadhyaya and Sarker (1963). A full description of the technique on multiple curvilinear regression is available in the book on *Methods of correlation and regression analysis* by Ezekiel and Fox (1957).

3. Meteorological factors

The rabi crop is sown at Raichur by middle of October after the receipt of October rains. The crop thrives mostly on the moisture stored in the soil. The soil of the locality is medium black of heavy loam with good water holding capacity. The rainfall for 8 weeks prior to sowing was taken into consideration and this was found to have a significant influence on the crop growth and yield.

As the crop is grown in the winter season, temperature especially during its repid period of growth may be another important weather factor influencing the yield. Therefore for evolving the yield forecast formula, the maximum temperature and minimum temperature for a period of 8 weeks including the week of sowing were taken into account. As the crop is grown during the clear winter season, sunshine and humidity were not taken into account.

4. Multiple regression

The combined effect of all the meteorological factors x_1 to x_p may be had from a regression equation (Goulden 1962) of the form :

$$Y_e = a + b_1x_1 + b_2x_2 + \ldots\ldots\ldots + b_p x_p \qquad (1)$$

where Y_e is the expected value of the dependent variable, a the constant, b_i the regression coefficient of x_i the independent variable. The regression equations obtained in the present study are :

(*i*) $E(Y) = -907{\cdot}9 + 114{\cdot}119\ M - 0{\cdot}845\ R - 15{\cdot}159\ D - 59{\cdot}341\ N$

for the variety M35-1 with multiple C. C. of 0·544.

(*ii*) $E(Y) = -2590{\cdot}0 + 210{\cdot}205M - 0{\cdot}801\ R - 6{\cdot}915D - 140{\cdot}40\ N$

for the other variety PJ-4R with multiple C. C. of 0·542.

$E(Y)$ is the expected yield; M, mean maximum temperature in degrees centigrade; R, the total rainfall in millimetres; D, the number of rainy days and N, the mean minimum temperature in degrees centigrade.

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TABLE 1

Deviations of the actual yield from the regression line for the linear and the curvilinear functions

Year	Variety M 35-1				Variety PJ-4R			
	Linear	Curvilinear freehand curve			Linear	Curvilinear freehand curve		
		First curve	Final curve	Next to final curve		First curve	Final curve	Next to final curve
1948-49	—216	—13	—64	43	171	314	420	451
-50	—258	—244	—165	—188	—137	—164	—326	—347
-51	—419	—475	84	—179	—546	—426	50	41
-52	—64	122	61	163	—76	354	225	381
-53	546	506	235	287	296	176	67	173
-54	430	193	17	—66	170	—153	—242	—401
-55	—98	260	—84	21	—222	—10	—30	1
-56	—242	—194	45	47	255	—132	—56	—10
-57	—424	—160	—206	—114	—335	—184	—148	—77
-58	—394	—117	—163	—46	—561	—158	—177	—21
-59	335	75	—81	51	275	—39	—8	—187
-60	26	—169	—80	97	—41	—269	—13	3
1962-63	431	181	25	17	52	—71	—200	—409
-64	—173	—402	—98	—201	—294	—722	—436	—360
-65	318	150	199	101	288	282	103	149
-66	—385	—76	—22	—65	—63	302	318	354
-67	654	277	136	28	1196	898	454	265
Sum of squares	2184729	1071580	257469	268200	2851848	2140508	1005609	1217454
Total sum of squares			3,102,156				4,035,012	

5. Multiple curvilinear regression

The linear multiple regression is the starting point for working out the method of successive approximations given by Ezekiel and Fox (1959). Table 1 gives the deviations of the actual yield from the regression line for the linear and the curvilinear functions after the first, final and next to final approximations. The penultimate row gives the sum of squares of these deviations which is a measure of the efficiency of these regressions, while the last row indicates the total sum of squares of deviation from the mean.

6 Estimation and correction curves

From an inspection of the partial regression coefficients and the final curve, maximum temperature appears to have highly significant influence on yield. Therefore, this was selected as prime factor whose function may be expressed as follows:

$$X_e' = f_M(X_M) - M_f(M) + X \qquad (2)$$

where X_e' is the estimated yield from the prime factor, $f_M(X_M)$ is the general function measuring any regular change in the dependent variable (in this case maximum temperature which can be

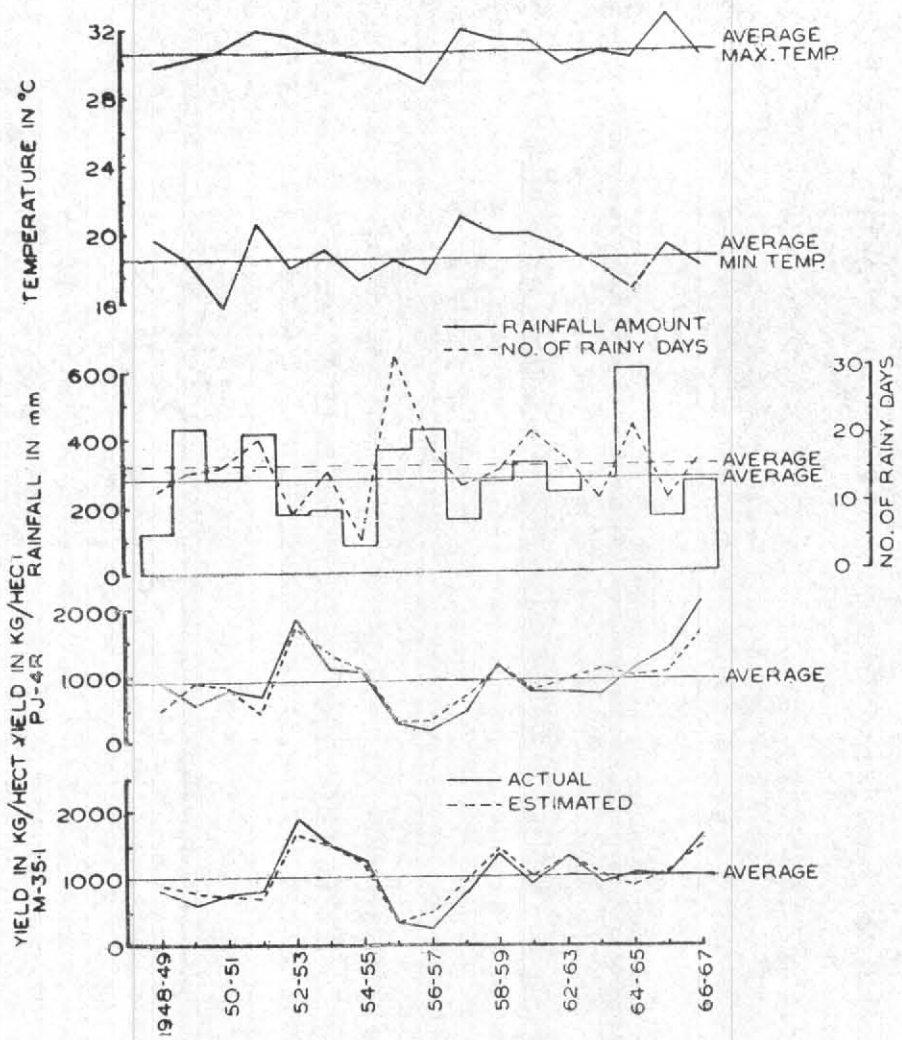

Fig. 1

Yield (actual and estimated) against the meteorological factors

described by a curve), M_f (M) is the mean of all values read from the final curve for maximum temperatures and X is the mean of the dependent variable. This function for the variety M35-1 is

$$X_e' = f_M(X_M) - 947{\cdot}6 + 1006{\cdot}7$$
$$= f_M(X_M) - 985{\cdot}9 + 902{\cdot}4$$
$$= f_M(X_M) - 83{\cdot}5$$

These equations and the expected yield values for the two varieties are indicated in Table 2.

For the remaining independent factors their effect is given as a correction to be made to the expected yield obtained from the equation (2). This correction formula may be stated as follows:

$$X_i' = f_i\,(X_i) - M_{fi}$$

where i stands for any one of the remaining variables.

The equations for these independent variables to arrive at the respective corrections, are given in Tables 3, 4 and 5 for rainfall (R), number of rainy days (D) and minimum temperature (N) along with the expected yield for the varying values of these independent factors.

The corresponding estimations under three correction curves for each variety are given in Fig. 2.

7. Estimation of yield from curvilinear regression

The estimated yield values from maximum temperature curve were corrected for variations in other three sets of independent variables. These values as well as the actual yield are shown in Fig. 1 along with the meteorological factors.

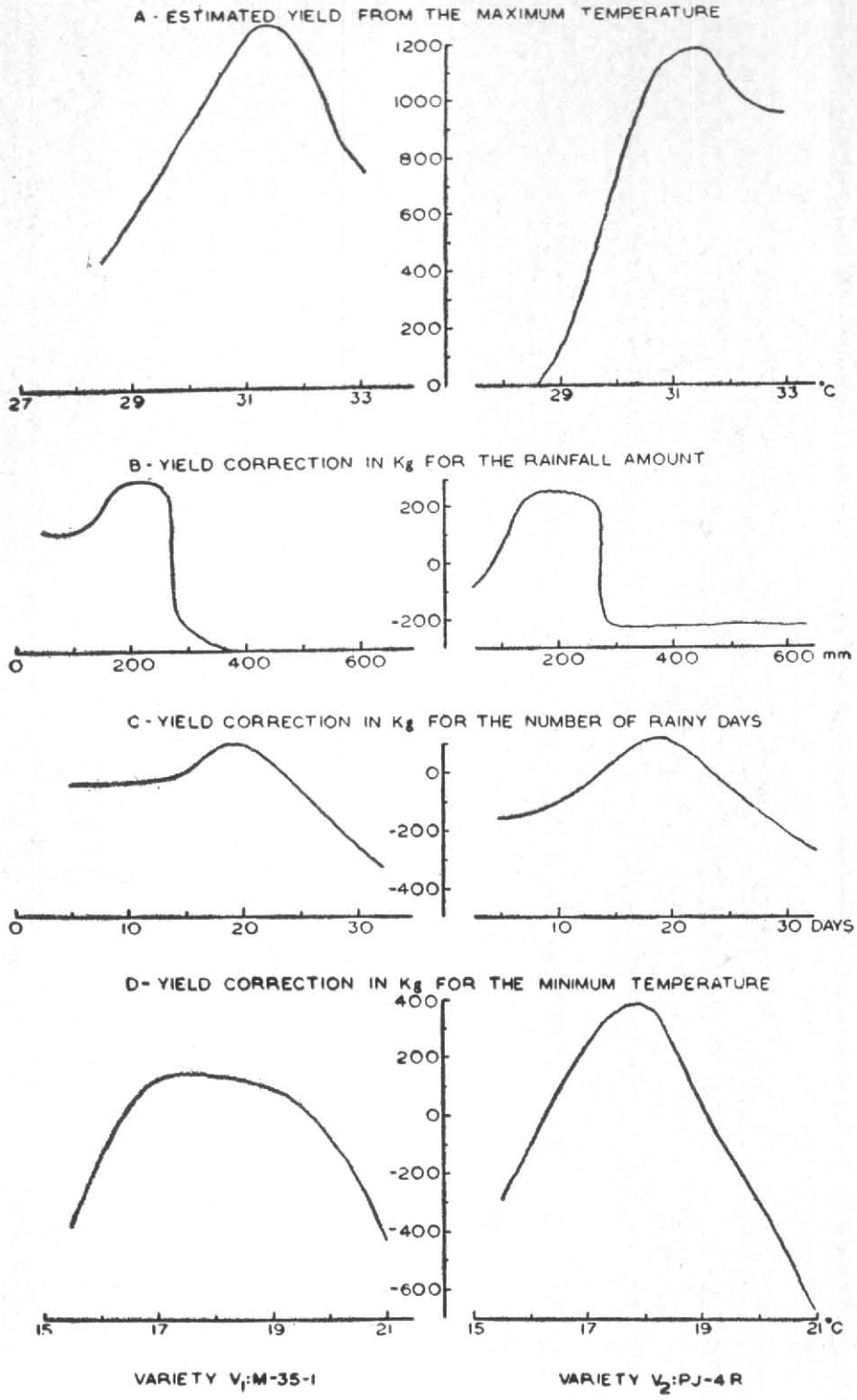

Fig. 2
Yield response curves

TABLE 2

Equations and the expected yield values of grain for maximum temperature

Maximum temp. (°C)	Equation for the curve $X_e' = f_M(X_M) + 59 \cdot 1$ — Expected yield in kg of variety M 35-1	Equation for the curve $X_e' = f_M(X_M) - 83 \cdot 5$ — Expected yield in kg of variety PJ-4R
28·7	509	17
29·0	589	122
29·5		417
30·0	904	752
30·5	1,064	1,027
31·0	1,229	1,162
31·5	1,269	1,182
32·0	1,159	1,057
32·5	924	972
33·0	759	957

TABLE 3

Equations and the corrections to the expected yield for varying rainfall

Rainfall (mm)	Equation for the curve $X_1' = f_R(X_R) - 1017 \cdot 6$ — Correction to expected yield (Variety M35-1)	Equation for the curve $X_1' = f_R(X_R) - 900 \cdot 6$ — Correction to expected yield (Variety PJ-4R)
50	112	—81
100	112	49
150	182	239
200	302	249
250	282	224
300	—218	—221
350	—278	—221
400	—293	—221
450	—298	—221
500	—298	—221
600	—298	—221

TABLE 4

Equations and corrections to the expected yield for varying number of rainy days

No. of rainy days	Equation for the curve $X_2' = f_D(X_D) - 990 \cdot 6$ — Correction to expected yield (Variety M 35-1)	Equation for the curve $X_2' = f_D(X_D) - 1006 \cdot 2$ — Correction to expected yield (Variety PJ-4R)
5	—51	—156
10	—41	—106
15	4	49
20	99	109
25	—61	—56
30	—261	—206
35	—421	—306

TABLE 5

Equations and corrections to the expected yield for varying minimum temperatures

Minimum temp. (°C)	Equation for the curve $X_3' = f_N(X_N) - 994 \cdot 0$ — Correction to expected yield (Variety M35-1)	Equation for the curve $X_3' = f_N(X_N) - 881 \cdot 8$ — Correction to expected yield (Variety PJ-4R)
15·5	—374	—282
16·0	—144	—82
16·5	46	108
17·0	126	268
17·5	146	363
18·0	146	388
18·5	126	238
19·0	91	18
19·5	41	—152
20·0	—84	—368
20·5	—219	—482
21·0	—444	—662

TABLE 6

Maximum temperature	Response in kg/hac.	
	Variety M35-1	Variety PJ-4R
Lowest (28·7° C)	510	18
Optimum (31·4° C)	1270	1185
Highest (32·9° C)	795	950

The multiple correlation coefficient is calculated from the formula

$$I^2_{1\cdot2,3\cdots k} = \frac{1-S_1^2 f\ (2,3,..k)}{S_1^2}$$

where $S_1\ f(2,3....k)$ is the standard deviation of the residuals and S_1^2 is the standard deviations of the independent variables. The values are 0·958 for the variety M35-1 and 0·801 for the variety PJ-4R.

8. Relative efficiency of multiple regressions

The multiple correlation coefficient (MCC) by linear method is of the order of 0·54 while the indices of curvilinear multiple correlation (ICMC) are 0·958 for M35-1 and 0·801 for PJ-4R. This improvement by the curvilinear technique is mainly due to a better fit of the yield values to the meteorological values on the curvilinear line falling further away from the linear regression line. Thus in 1950-51 the maximum temperature was distinctly lower than in other years and in 1952-53 it was optimum and the yield estimates are better. However in the year 1963-64, the weather conditions were favourable but the yields were low due to missing the normal date of sowing by two weeks.

9. Curvilinear relationship between yield and weather factors

From a comparative study of the curves in Fig. 2 it may be inferred that the pattern and magnitude of responses of the crop to these four weather factors differ among themselves, the temperatures showing greater influence than rainfall. Also the two varieties show a differential curvilinear response for the recorded range of weather factors. The estimated yield values for the recorded range of maximum temperatures are given in Table 6.

10. Discussion

In an earlier correlation study on crop-weather relationship—sugarcane, Gangopadhyaya and Sarker (1963) came to the conclusion that although the linear partial correlation is a definite improvement over linear correlation the detailed information as to the behaviour of the crop in relation to weather cannot be obtained from such a linear study. The present paper confirms the advantage of a curvilinear multiple correlation.

From a study on the influence of weather on wheat yield at Dharwar which is about 250 kilometres west of Raichur, Ramamurthi and Banerjee (1966) found that the optimum weather factors are (*a*) 500 mm of rainfall, (*b*) 29·2°C of maximum temperature, and (*c*) 16·0°C of minimum temperature. The present paper on rabi jowar indicates that these optimum values for M35-1 variety are (*a*) 275 mm of rainfall, (*b*) 31·4°C of maximum temperature, and (*c*) 17·5°C of minimum temperature. Thus the winter jowar is better suited for arid tracts with somewhat higher tempertures than the wheat crop.

Acknowledgement

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Appendix

Basic data of yield of grain and meteorological factors

Year	Yield of grain				Std. week of sowing	Meteorological factors			
	Variety M 35-1		Variety PJ-4R			Total rainfall for 8 weeks prior to sowing		Average temperature (°C) for 8 weeks after sowing	
	Actual in kg/ hectare	Per cent	Actual in kg/ hectare	Per cent		Amount (mm)	No. of rainy days	Max.	Min.
1948-49	817	81	883	98	43	115·6	12	29·7	19·7
-50	581	58	555	62	42	430·0	15	30·1	18·5
-51	755	75	758	84	43	279·1	16	30·6	15·7
-52	787	78	663	73	41	414·0	20	31·9	20·7
-53	1876	186	1785	198	41	173·4	9	31·5	18·1
-54	1493	148	1076	119	41	189·1	15	30·6	19·1
-55	1280	127	1028	114	42	82·6	5	30·3	17·3
-56	341	34	272	30	42	366·2	32	29·7	18·6
-57	245	24	150	17	45	426·0	19	28·7	17·7
-58	763	76	391	43	41	156·8	13	31·9	21·0
-59	1355	135	1135	26	42	271·6	15	31·3	20·0
-60	911	90	735	81	42	324·4	21	31·3	20·0
1962-63	1326	132	723	80	42	237·8	17	29·8	19·2
-64	928	92	692	77	44	280·3	11	30·6	18·2
-65	1025	102	1071	119	43	606·3	22	30·3	16·8
-66	1004	100	1331	147	41	165·2	11	32·9	19·4
-67	1627	162	2092	232	43	271·6	18	30·3	18·1
Mean	1007	100	902	100	42·2	281·8	15·9	30·7	18·7