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Effect of weather on rice crop in Bhandara district : A curvilinear approach

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सार — वर्षा, अधिकतम तापमान और सापेक्षिक आर्द्रता के प्रभाव के परीक्षण के लिए भण्डारा जिले (महाराष्ट्र) में चावल की फसल पर वक्ररेखी तकनीक प्रयुक्त की गई है। इन तीन कारकों के संयुक्त प्रभाव को देखते हुए चावल की फसल के आकलन के लिए आंशिक समाश्रयण वक्र का पता लगाया गया। यह देखा गया कि सक्रिय वृद्धि के दौरान की अवधि में इस क्रम में अधिकतम तापमान और सापेक्षिक आर्द्रता के बाद वर्षा महत्वपूर्ण कारक है। सक्रिय वृद्धि की अवस्था के दौरान कुल वर्षा का ईष्टतम मान 1000 मि. मी. और अधिकतम तापमान और सापेक्षिक आर्द्रता क्रमशः 30.5° से. और 81% पाए गए।

ABSTRACT. Curvilinear technique has been applied to rice crop in Bhandara district (Maharashtra) to examine effects of rainfall, maximum temperature and relative humidity. Partial regression curves for estimating the rice yield by taking into account the combined effect of these three factors have been worked out. It is observed that during the period of active growth rainfall is the most significant factor followed by maximum temperature and relative humidity in that order. The optimum value of total rainfall during the active growth phase was found as 1000 mm and those for maximum temperature and relative humidity as 30.5° C and 81% respectively.

Key words — Transplanting, flowering, curvilinear, residual, regression curves, approximation.

1. Introduction

Rice (*Oryza sativa L*) is a water loving plant widely grown during the summer monsoon in Maharashtra mostly as a rainfed crop. The crop is usually sown in nursary in 3rd/4th week of June and transplanted when the seedlings are two to three weeks old. The early variety matures in about 120 days while the medium one takes a little more time. Though principally a tropical crop, rice requires abundance of water, (Huke 1976) high temperature and humidity (Ghosh 1970) during its growth cycle; in particular, the period of flowering, depends on temperature and humidity (Grist 1959). Therefore, these three weather factors have a marked bearing on the growth and yield of rice.

In this paper an attempt has been made to find out how rainfall, maximum temperature and relative humidity effect development and production of rice crop.

2. Data used

The present study pertains to Bhandara district in eastern Maharashtra. This district alone produces about one-fifth of total rice production in the State. With very limited irrigation, the crop has to depend entirely on natural rainfall. The following table gives the rainfall particulars for this district:

	Rainfall (mm)	Rainy days	Potential evapotrans-piration (mm)
Jun	203.8	9.3	169.3
Jul	177.7	18.1	110.3
Aug	399.4	15.7	102.1
Sep	209.1	10.7	107.1

In this district, the paddy is normally transplanted during 28th (8-15 July) standard week; elongation occurs around 29th (16-23 July) standard week. Flowering takes place in 39th (23-30 September) week while grain formation takes place around 40th (1-7 October) week. Thus the active growth period may be considered as between 29th to 40th standard weeks (*i.e.*, 16 July to 7 October).

Rainfall, temperature and humidity data for the above period were collected for the period 1965-87 for Gondia — the only observatory in the district. The crop data from 1965-87 were collected from *Agricultural Situation in India* published by Ministry of Food and Agriculture, New Delhi.

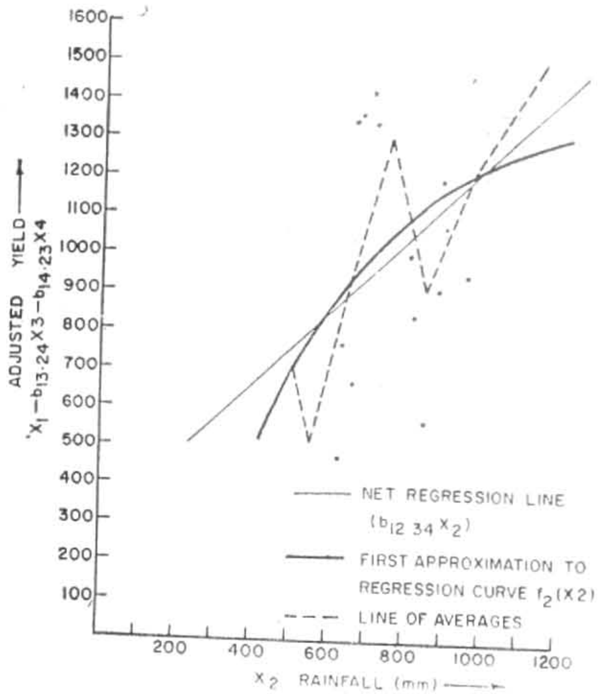

Fig. 1. Apparent relation of rice yield to rainfall adjusted to max. temp. and humidity

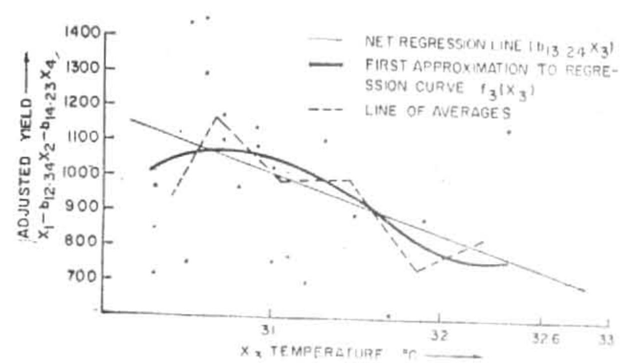

Fig. 2. Max. temperature and yield adjusted to humidity and rainfall

3. Past studies

Gangopadhyay and Sarker (1965) applied Fisher's technique to find out effect of rainfall on wheat crop. Statistical analysis by Fisher's curves was attempted by Sreenivasan and Banerjee (1973) who found that rice crop at Karjat responds favourably to rainfall during panicle initiation. The technique was also applied by Shaha and Banerjee (1975) to cotton at Coimbatore. Sreenivasan and Banerjee (1978) applying the same technique found that additional rainfall above the normal, exerts negative influence during sowing, tillering and flowering stages of rice at Adhutarai and Coimbatore. Studies by Rupa Kumar and Subbaramyya (1984) and Rupa Kumar (1986) for rice crop at Anakapalle revealed that heavy rainfall, high humidity and lower maximum temperature during vegetative growth stage, are favourable for the crop.

TABLE 1

Yield of rice, rainfall, temperature and relative humidity of Bhandara for kharif season and yield estimated by linear regressions of three factors

Year	Total rainfall X_2 (mm)	Daily average maximum temperature X_3 (°C)	Daily average RH X_4 (%)	Yield X_1 (kg/ha)	Estimated yield X'_1 (kg/ha)	$X_1 - X'_1 = z'$
1965	626.1	31.7	79.5	477	766.91	—289.91
1966	849.4	32.3	78.1	570	885.89	—315.89
1967	883.1	30.3	84.1	913	1218.68	—305.68
1968	961.0	31.1	81.8	950	1171.55	—221.55
1969	898.1	30.3	82.9	1070	1239.55	—169.55
1970	974.4	31.0	82.5	1210	1197.06	12.94
1971	806.9	30.8	80.1	1000	1085.19	—85.19
1972	569.1	31.2	80.8	520	789.26	—269.26
1973	619.1	30.3	83.8	920	970.34	—50.34
1974	634.4	31.9	77.8	770	750.79	19.21
1975	960.2	30.6	82.0	1470	1253.23	216.77
1976	713.1	30.7	82.1	1120	1001.95	118.05
1977	667.3	30.6	80.0	1370	986.96	383.04
1978	891.8	30.9	81.0	1200	1143.88	56.12
1979	488.6	32.4	77.3	897	531.94	365.06
1980	708.1	31.1	80.9	1431	937.05	493.95
1981	709.1	31.4	80.3	1345	891.20	453.80
1982	822.5	31.0	74.5	845	1097.65	—252.65
1983	1186.8	30.9	82.7	1544	1413.80	130.20
1984	657.5	30.5	75.0	671	1022.16	—351.16
1985	657.5	30.5	76.5	1351	1013.83	337.17
1986	790.5	31.3	75.1	1165	1013.88	151.12
1987	449.2	31.5	80.2	203	628.91	—425.91

All the studies cited above have used Fisher's technique or its modification in some form to study the influence of weather on crops. No attempt, except by Gangopadhyay and Sarker (1964 a & b), appears to have been made in India to apply curvilinear technique and find out if there is any optimum point for growth, with respect to the weather elements.

4. Technique

In crop-weather relationship studies using simple linear regression, it is presumed that the effect of an unit rise or fall of weather element exerts constant effect on the yield. Crop growth can not, at all phases, be expressed by linear correlation. There is definitely some stage of the crop growth after which any change (rise or fall) in the weather factor, influences the crop in opposite way. In order to find effect of a weather variable, resort has to be taken to curvilinear rather than linear analysis (Ezekiel and Fox 1959).

If X_1 is the yield and X_i (where, i=2, 3,. .) are the independent weather factors upon which the crop growth and yield depends, then

$$X_1 = a + f_2(X_2) + f_3(X_3) + f_4(X_4) + \ldots\ldots$$

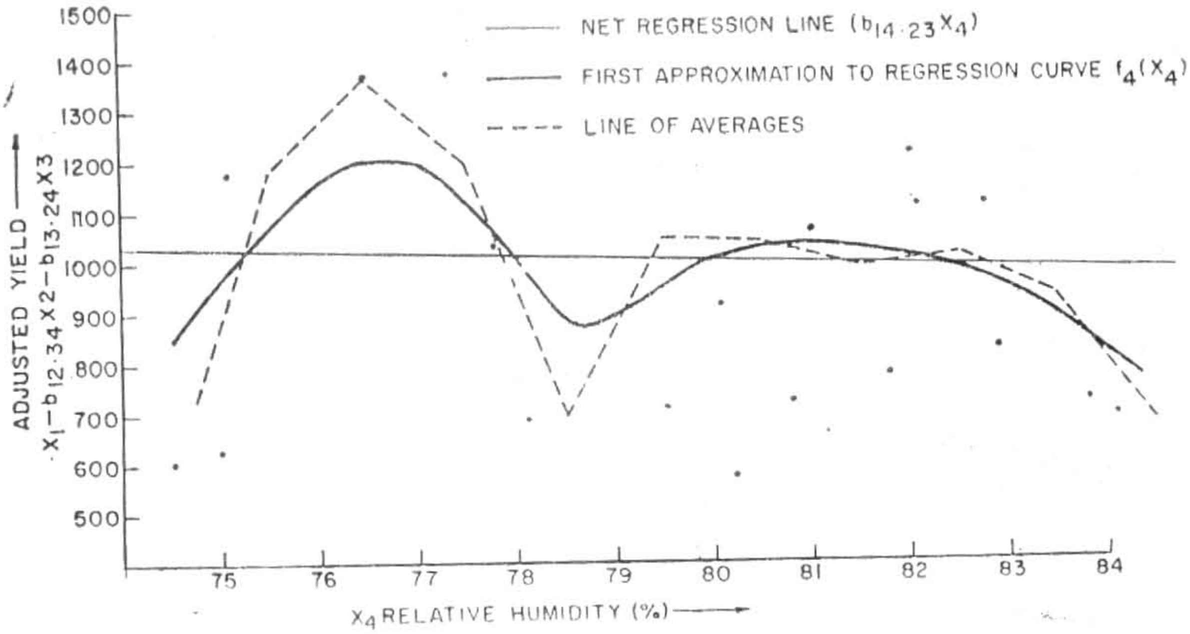

Fig. 3. Relative humidity and yield adjusted to max. temp. and rainfall

Here, the function $f_2(X_2)$ is a partial regression function which represents a change in X_1 corresponding to change in X_2. The function $f_2(X_2)$ could be a straight line or a curve. The curves $f_3(X_3)$ and $f_4(X_4)$ have similar meaning. The aim is to determine the shape of the function. This is accomplished by graphical method of successive approximation.

4.1. *First approximation curves*

Table 1 contains mean yield, rainfall, temperature and humidity data. The yield data is presumed to belong to the same population neglecting the changes in the varieties, agronomic practices etc. Preliminary analysis of the data, from Mann-Kendall statistics revealed absence of any trend. Thus the assumption made above appears justified.

The highest linear correlation was found between X_1 and X_2 which was 0.54 showing that the yields are definitely linked to the variation in rainfall. The regression was:

$$X_1 = 163.478 + 1.099\ X_2 \qquad (1)$$

Next, a linear multiple correlation between X_1 the dependent variable and X_2, X_3 and X_4, the independent parameters were worked out. The multiple correlation, $R_{1\cdot234}=0.6016$ was significant and the resulting regression was

$$X_1 = 5912.707 + 0.947\ X_2 - 167.102\ X_3 - 5.555\ X_4 \qquad (2)$$

This shows that when the linear influence of temperature and humidity is allowed for, the yield increases by 9.47 kg per hect. for 1 cm increase in rainfall, whereas before these two factors (temperature and humidity) were taken into account, yield increased by 10.99 kg, with additional cm of rainfall. If other factors have so much effect on the average linear relationship, they should have an even greater effect on the shape of the curves.

Yield estimates X_1 were calculated for each of 23 observations from which the residuals $z' = X_1 - X'_1$ were noted. These are also given in Table 1.

Next, we try to find the relation between variations in X_2 and variations in X_1 after the association between X_1 & X_3 and X_1 & X_4 have been eliminated. For this purpose net regression line for X_1 and X_2 is plotted (Fig. 1). This is achieved by writing

$$X_1 = 5912.707 + 0.947\ X_2 - 167.102\ M_3 - 5.555\ M_4 \qquad (3)$$

where, M_3 and M_4 are means for X_3 and X_4 respectively. The equation thus finally becomes

$$X_1 = 278.34 + 0.947\ X_2 \qquad (4)$$

The residuals from each observation (Table 1) are then plotted on the chart with X_2 values as abscissa and z' as ordinate and the net regression as zero base.

Consideration of Fig. 1 is facilitated by computing the means of the ordinates corresponding to the values of X_2 falling within convenient intervals. This could be obtained by simply averaging together z' values for selected groups of X_2 and plotting these as deviation from the regression line. These averages are plotted in the same manner as individual observations and are shown in Fig. 1 as broken line. A free hand curve is drawn passing as near to the groups averages as is consistent with a continuous smooth curve and yet confirming to the limiting conditions as to its shape. This curve is the first approximation to the curvilinear function

$$X_1 = f_2\ (X_2)$$

This is only a first approximation since it has been determined while allowing for only the net linear effects of the other two variables.

In exactly the same manner first approximate curves $X_1 = f_3\ (X_3)$ and $X_1 = f_4\ (X_4)$ are drawn. They are shown in Figs. 2 & 3.

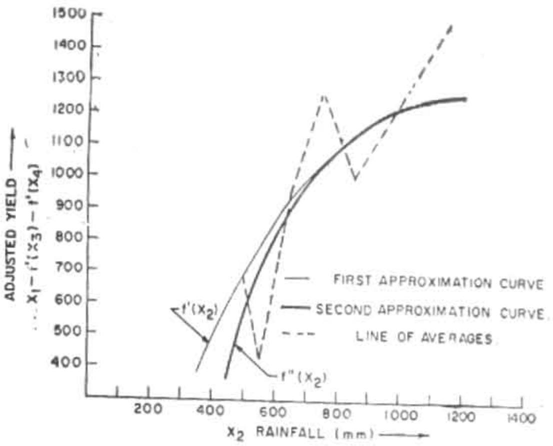

Fig. 4. Rainfall and yield adjusted to temp. and humidity on the basis of second approximation curve

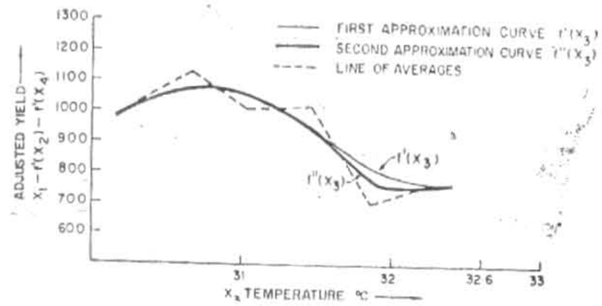

Fig. 5. Max. temp. and yield adjusted to rainfall and humidity on the basis of second approximation curves

TABLE 2

Computations of X_1'''' from the third approximation curves and the residuals z'''' (1965-1987)

X_2	X_3	X_4	$f_2'''(X_2)$	$f_3'''(X_3)$	$f_4'''(X_4)$	$\Sigma(f''')$	$\Sigma(f''')+a = X_1'''$	X_1	$(X_1 - X'''') = z''''$
626.1	31.7	79.5	855	910	910	2675	686.7	477	—209.7
849.4	32.3	78.1	1138	820	915	2873	884.7	570	—314.7
883.1	30.3	84.1	1160	1035	830	3025	1036.7	913	—123.7
961.0	31.1	81.8	1200	1040	1040	3280	1291.7	950	—341.7
898.1	30.3	82.9	1170	1035	960	3165	1176.7	1070	—106.7
974.4	31.0	82.5	1215	1090	990	3255	1266.7	1210	—56.7
806.9	30.8	80.1	1100	1065	1020	3185	1196.7	1000	—196.7
569.1	31.2	80.8	720	1020	1075	2815	826.7	520	—306.7
619.1	30.3	83.8	830	1035	875	2740	751.7	920	168.3
634.4	31.9	77.8	875	860	1005	2740	751.7	770	18.3
960.2	30.6	82.0	1200	1060	1030	3290	1301.7	1470	168.3
713.1	30.7	82.1	980	1065	1025	3070	1081.7	1120	38.3
667.3	30.6	80.0	920	1060	1005	2985	996.7	1370	373.3
891.8	30.9	81.0	1165	1060	1075	3300	1311.7	1200	—111.7
488.6	32.4	77.3	450	830	1250	2530	541.7	897	355.3
708.1	31.1	80.9	980	1040	1075	3095	1106.7	1431	324.3
709.1	31.4	80.3	980	990	1045	3015	1026.7	1345	318.3
822.5	31.0	74.5	1110	1050	770	2930	941.7	845	—96.7
1186.8	30.9	82.7	1235	1060	975	3270	1281.7	1544	262.3
657.5	30.5	75.0	910	1060	900	2870	881.7	671	—210.7
657.5	30.5	76.5	910	1060	1385	3355	1366.7	1351	—15.7
790.5	31.3	75.1	1085	1010	920	3015	1026.7	1165	138.3
449.2	31.5	80.2	260	965	1040	2265	276.7	203	—73.7

It may be seen from the first approximation curves that effect of rainfall, maximum temperature and relative humidity on yield is not linear but at some point it attains peak.

4.2. *Estimates of X_1 from the first approximate curves*

The curvilinear relations enable us to estimate X_1. For this, we designate relation between X_1 with X_2 in Fig. 1 as $f_2'(X_2)$ between X_1 and X_3 as $f_3'(X_3)$ (Fig. 2) and X_1 and X_4 as $f_4'(X_4)$ vide Fig. 3. Expressing esimates of X_1 now as X_1'' we get

$$X_1'' = a'_{1\cdot 234} + f_2'(X_2) + f_3'(X_3) + f_4'(X_4) \quad (5)$$

$$a'_{1\cdot 234} = M_1 - \Sigma\,[f_2'(X_2) + f_3'(X_3) + f_4'(X_4)]/n \quad (6)$$

n=Number of observation, M_1= Mean of X_1

The values of f' were picked from the corresponding values of X_2, X_3 and X_4 and substituted in Eqn. (6), we get :

$$a'_{1\cdot 234} = 1000.52 - \frac{3010.3}{23} = -2009.8$$

From this X_1'' can be computed.

The next step is to examine if the new estimates, X''_1 come nearer to reproducing observed values of X_1 than did the first set of estimates based on the linear regression equation. For this purpose a new set of residuals are computed as given below

$$z'' = X_1 - X_1''$$

Comparing z' with z'' it is seen that the new residuals are smaller than the previous one, in 17 cases and only in 6 cases they are larger. For a more accurate comparision the adjusted standard deviations (SD) were worked out. The linear multiple correlation uses 4 d.f. and so the adjusted SD for

$$z' = \Sigma z'^2 / (23-4) = 303.83$$

For z'' which has 7 d.f. the adjusted S.D., $\dfrac{\Sigma z''^2}{23-7} = 280.75$

It is obvious that the new estimates are nearer to the observed values than the first set of estimates.

4.3. *Second approximate net regression curves*

The first approximate curves from Figs. 1-3 are drawn again. Next, the residuals z'' are now plotted as deviations just as before except that now the residuals are plotted as deviation from regression curve instead of from regression lines. Residuals are then averaged in groups employing the same grouping as before which eliminate the need of averaging the corresponding values of X_2 over again.

The estimate X_1''' are then calculated as

$$X_1''' = a_1''_{\cdot 234} + f_2''(X_2) + f_3''(X_3) + f_4''(X_4) \quad (7)$$

where,

$$a_1''_{\cdot 234} = M_1 - \Sigma\,[f_2(X_2) + f_3(X_3) + f_4(X_4)]/n \quad (8)$$

The new residuals, $z''' = X_1 - X_1'''$

Comparison between z'' and z''' show that the new residuals decreased in 13 cases and increased in 10 cases. The new adjusted SD of $z''' = 276.64$.

Apparently the third approximations are more nearer to the actuals than the earlier ones.

4.4. *Further successive approximation*

The regression curves used in constructing the estimates X_1''' are the second approximations to the true curvilinear relationship determined by eliminating some of the linear/curvilinear effects of the other independent factors. From the residuals z''' obtained by the use of second approximate curves, we can determine, if any change in the shape of the curves is needed.

For this purpose, the curve obtained in preceding paragraphs were re-drawn. Residuals z''' are now plotted as deviations from the regression curve at points corresponding to the independent variable X_2. To facilitate drawing of curves, residuals z''' are again grouped as in Table 2, plotted and a free hand curve drawn. Very little changes are found necessary in the shape of the curve. The curve thus drawn is depicted in Fig. 4. In exactly the same manner curves in Figs. 5 & 6 are drawn.

A new set of residuals z'''' is computed by substracting the new estimates X_1'''' from the actual values of X_1 (Table 2). The adjusted SD for z'''' was 263.72 and indicates that the third approximates is more accurate than the earlier ones. The approximations was terminated at this stage, since the SD of z'''' is smaller than that of z''' and was felt that the curves have approached the underlying true curves.

The curves in Figs. 4-6 represent the net relationship between the rice yield and rainfall, maximum temperature and relative humidity and could be used to estimate the yield values. It is obvious from the linear correlations that rainfall is the most important factor followed by maximum temperature and relative humidity in that order.

In order to test the validity of the curves, the yield is estimated first from the most important factor, *i.e.*, rainfall, assuming $X_1=F_2(X_2)$ to designate values of X_1 estimated from the net curvilinear relation to X_2 the estimates of X, *i.e.*, X_1' is given by

$$X_1' = F_2(X_2) = f_2(X_2) - M_{f(2)} + M_1 \quad (9$$

where, $M_{f(2)}$ is the mean values obtained from the final curve $f_2(X_2)$ and M_1, the mean of X_1

$$X_1' = f_2(X_2) + 12.74 \quad (10)$$

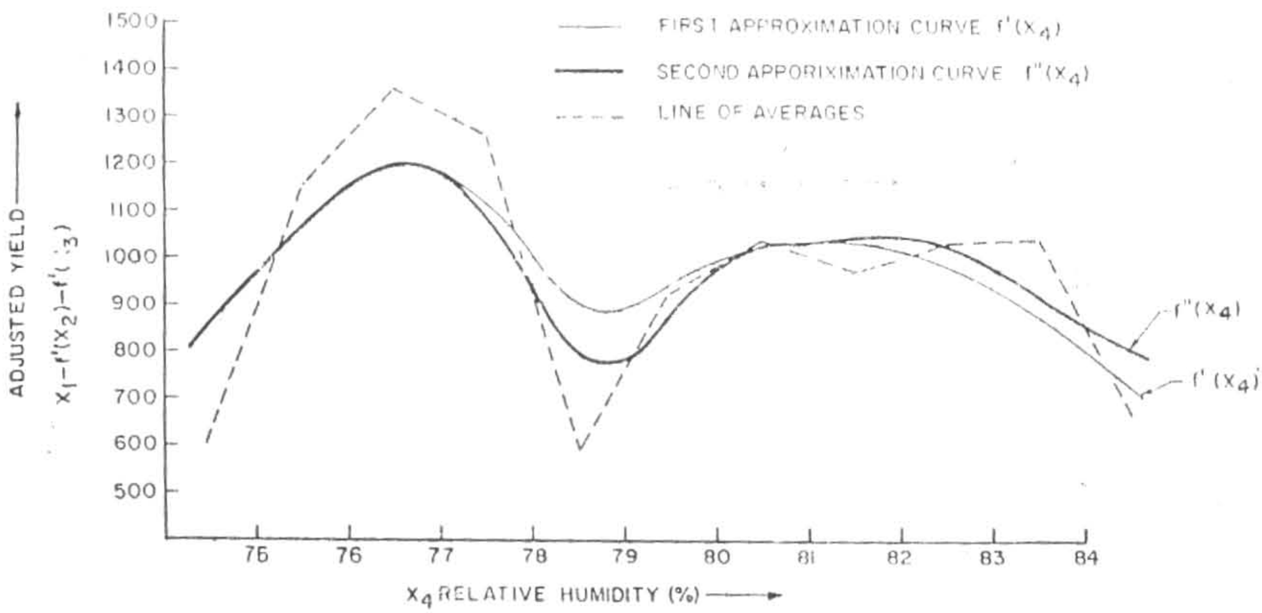

Fig. 6. Relative humidity and yield adjusted to rainfall and max. temp. on the basis of second approximation curves

TABLE 3

Estimated yield with varying rainfall and keeping maximum temperature and relative humidity constant

Rainfall X_2 (mm)	Reading from final curve $f'''(X_2)$	Constant $M_1-M_{f(2)}$	Average yield (kg/ha)
500	510	24.52	534.52
600	810	24.52	834.52
700	980	24.52	1004.52
800	1090	24.52	1114.52
900	1175	24.52	1199.52
1000	1220	24.52	1244.52
1100	1235	24.52	1259.52

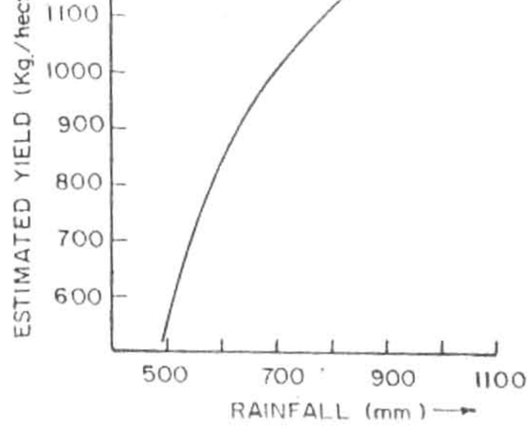

Fig. 7. Relation between estimated yield and rainfall

TABLE 4

Correction to yield due to differences in max'mum temperat-re

Average maximum temperature (°C)	Reading from final curve $f'''(X_3)$	Constant $-M_{f(3)}$	Correction to expected yield
30.5	1055	1007.83	47.17
31.0	1050	1007.83	42.17
31.5	960	1007.83	—47.83
32.0	840	1307.83	—167.80
32.5	845	1007.83	—162.83

TABLE 5

Correction to yield due to differences in relative humidity

Average relative humidity (%)	Reading from final curve $f'''(X_4)$	Constant $-M_{f(4)}$	Correction to expected yield
75	900	1005.0	—105
78	930	1005.0	—075
81	1070	1005.0	065
84	840	1005.0	—165

TABLE 6

Expected yield (kg/ha) with varying maximum temperature and relative humidity for rainfall 800 mm

Max. temp. (°C)	Relative humidity (%)			
	75	78	81	84
30.5	1056.69	1086.69	1226.69	996.69
31.0	1051.69	1081.69	1221.69	991.69
31.5	961.69	991.69	1131.69	901.69
32.0	841.69	871.69	1011.69	781.69
32.5	846.69	876.69	1016.69	786.69

The values estimated from Eqn. (10) are given in Table 3 alongwith different values of X_2 and shown in Fig. 7. These estimates are then corrected for X_3 and X_4. The correction for X_3 is given by

$$X'_1 = F_3(X_3) = f_3(X_3) - M_{f(3)} = f_3(X_3) - 995.87 \quad (11)$$

Correction for humidity is :

$$X'_1 = f_4(X_4) - M_{f(4)} = f_4(X_4) - 994.7 \quad (12)$$

As before $M_{f(3)}$ and $M_{f(4)}$ are the mean values obtained from the curves $f_3(X_3)$ and $f_4(X_4)$. These are given in Tables 4 & 5.

The yield can be estimated based on all the three independent factors by

$$X''_1 = F_2(X_2) + F_3(X_3) + F_4(X_4)$$

The yield estimates for particular values of rainfall *viz.*, 800 mm is given in Table 6. The table gives the most probable yield associated with any of the 20 different combination of maximum temperature and humidity. Combination of a table such as Table 6 with a statement of the extent to which yields averaged higher or lower than those shown at different times through the period enables to draw all conclusions from the study in a simple form.

5. Conclusion

The regression curves in this study show the net relationship between the yield and maximum temperature and relative humidity when the net variations associated with rainfall are held constant. It brings out the optimum value of rainfall for maximum rice yield. It may be emphasised that none of the three net regression curves could be approximated satisfactorily by straight lines and the curvilinear representation was the best that could be obtained.

The study also brings out the latent crop-weather relationship between rainfall, maximum temperature, relative humidity and the yield of rice crop in Bhandara district.

It is observed that combination of maximum temperature of 30.5°C, 81% relative humidity (*cf.* Ghosh 1970) and rainfall of 1000 mm during the physiological growth phases are ideally suited to give optimum rice crop yield.

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